Institute of Remote Sensing and Digital Earth
Chinese Academy of Sciences

ETWatch: Methods and Application

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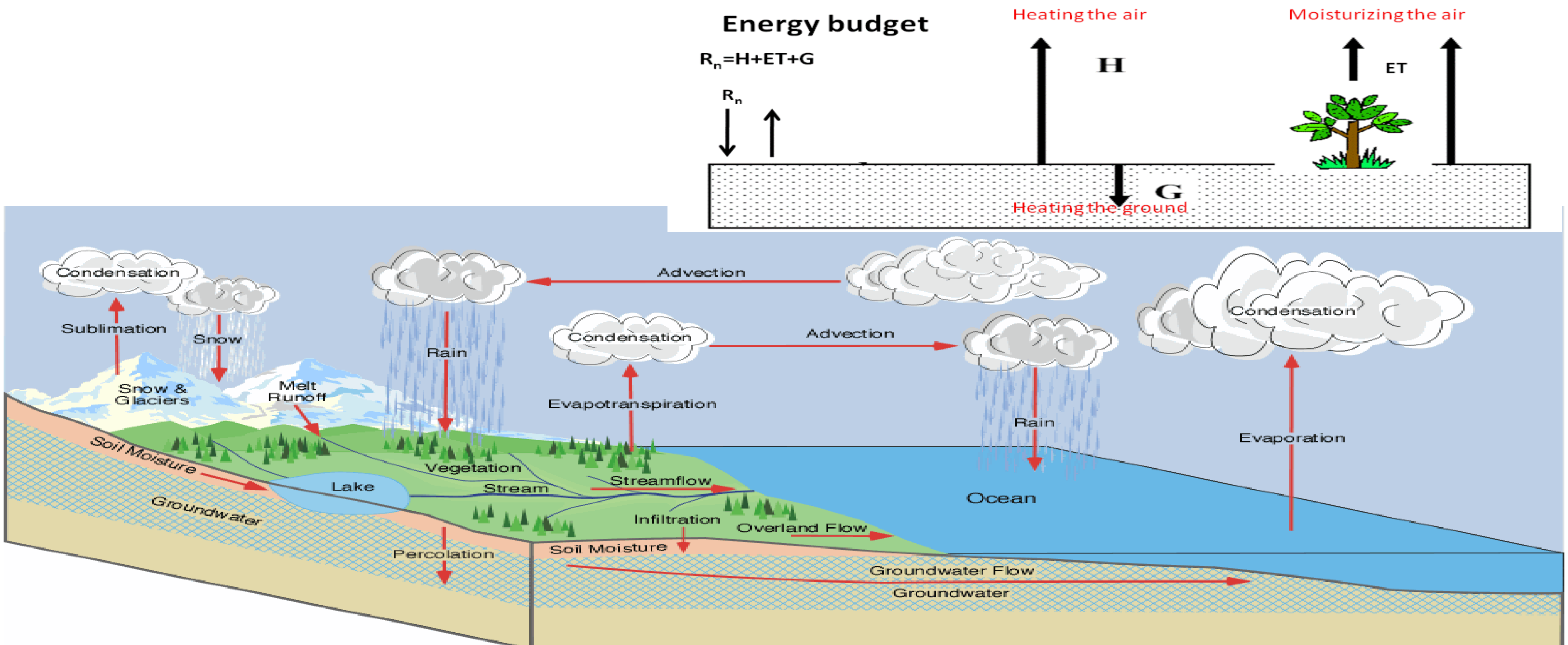
ET

Evapotranspiration: the canopy transpiration and soil evaporation

- ET is the actual water consumption.
- ET is the important segment of water circulation.
- ET is equally important to precipitation, hydrological observation.



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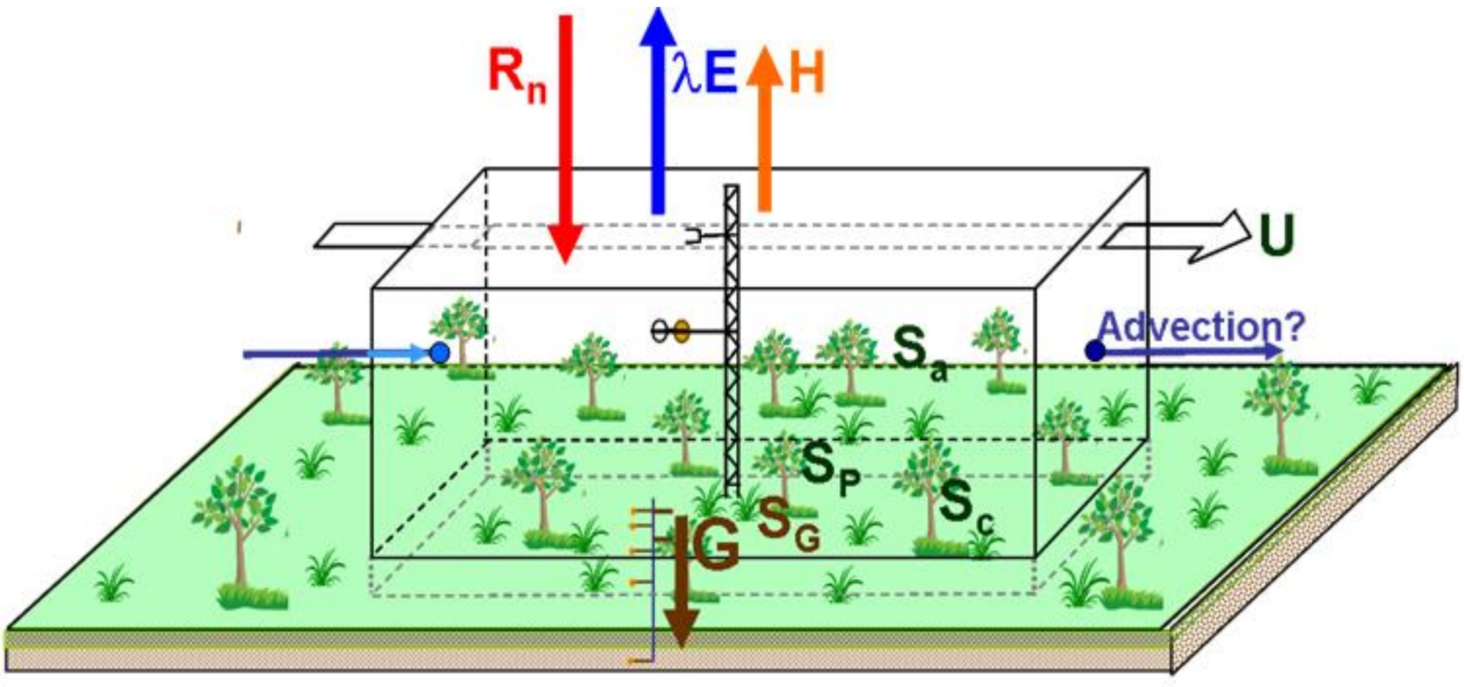
ETWatch Model

---- Parameterized model

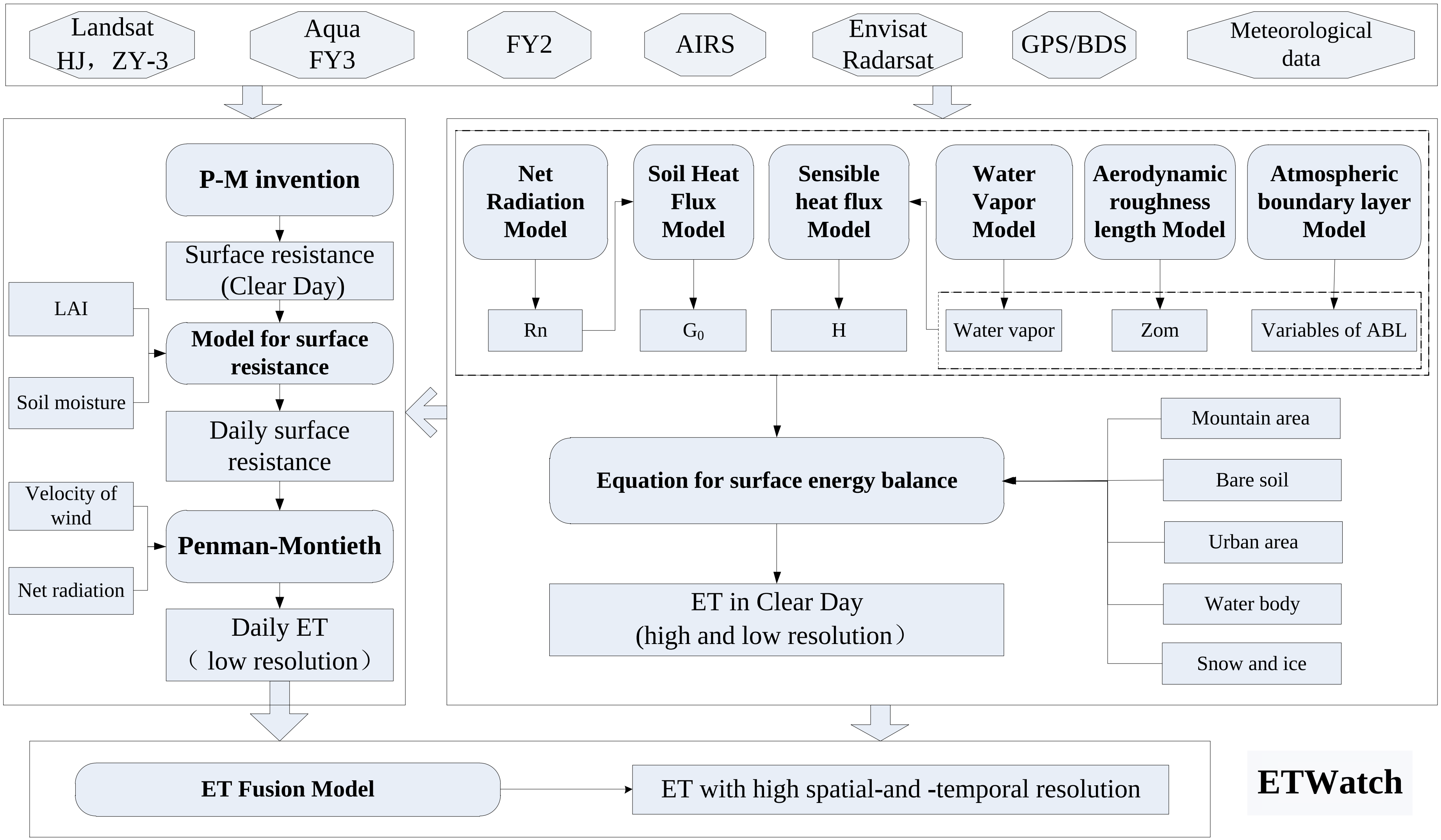
---- Multi-source satellite data

Energy Balance

$$R_n = \lambda E + H + G$$



ETWatch – operational remote sensing model



ETWatch Input data

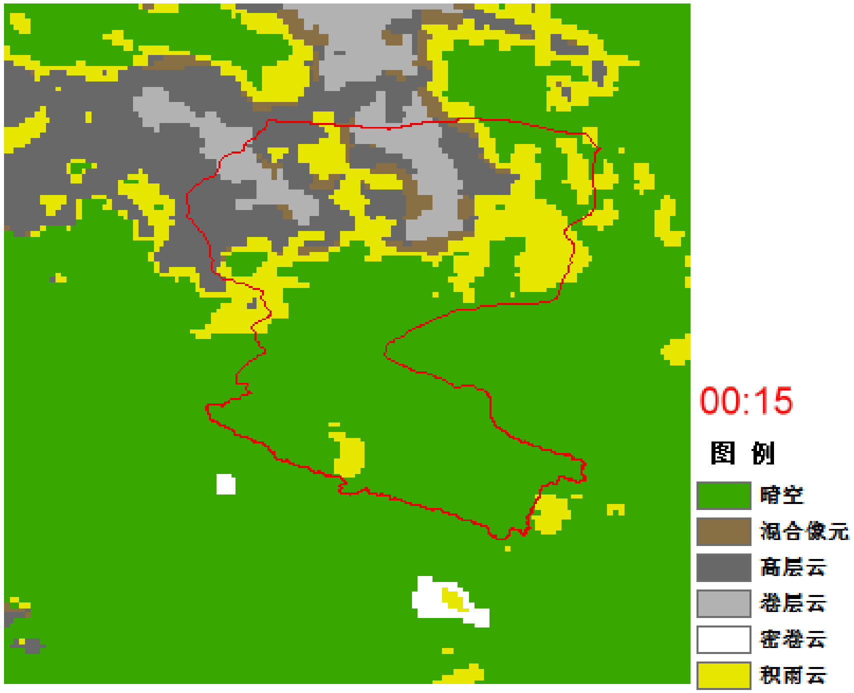
Parameter	Description	Source	Clear day	Cloud day
Rn	net radiation	RS+Meteo	○	○
G	soil heat flux	RS	○	×
H	Sensible heat flux	RS	○	×
rs	land surface resistance	RS+Meteo	○	○ With Surface Resistance model
es	Saturated vapour pressure	Meteo	○	○
ea	Actual vapour pressure	Meteo	○	○
ra	air dynamic resistance	Meteo	○	○
Z0m	aerodynamic roughness length	RS	○	○ With gap filing
NDVI	Normalized Difference Vegetation Index	RS	○	○ With S-G model
LST	Land surface temperature	RS	○	×
Albedo	Surface reflectivity of solar radiation	RS	○	○ With Filter method
LAI	Leaf Area Index	RS	○	○ With LAI-NDVI
Meteo parameters	Relative Humidity, Wind Velovity, Sun Shine Hours, Air Presure, Air Temperature	Meteo	○	○
ABL	Air temperature, Wind Velovity, Air Presurre and Humidity of Boudary Layers	RS	○	○
SM	Soil moisture	RS	○	○

Models in ETWatch

- Net-radiance
- Soil heat flux
- Aerodynamic roughness length
- Atmospheric Boundary Layer
- Vapor pressure deficit
- Sensible heat flux
- Surface resistance model: Daily Surface resistance (Rs)
- ET model on bare land, water body, snow and ice
- ET data fusion algorithm: data-fusion algorithm between high and low resolution data

Model of daily net radiation

Spatial distribution of FY-2D cloud product in Hei River Basin



Sunshine Factor (SF) base on cloud product

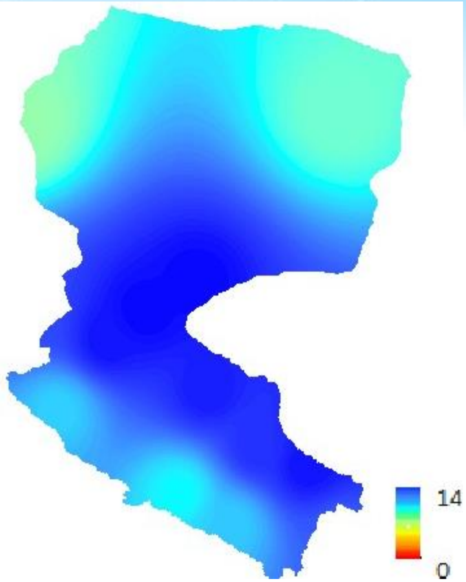
Value	Classification	SF
0/1	Clear Sky	0.86
11	Mixed Pixels	0.21
12	Altostrantus or nimbostratus	0.25
13	Cirrostratus	0.36
14	Cirrusdens	0.24
15	Cumulonimbus	0.13
21	Stratocumulus or altocumulus	0.1

- Traditionally , sunshine hours from meteorological station are used to calculate surface net radiation
- Now, The surface sunshine hours can be replaced by cloud information from geostationally meteorology satellite. It indicates more precise spatial distribution of surface net radiation
- The FY-2 cloud product was used to depict the sunshine changes every hour based on Sunshine Factor .

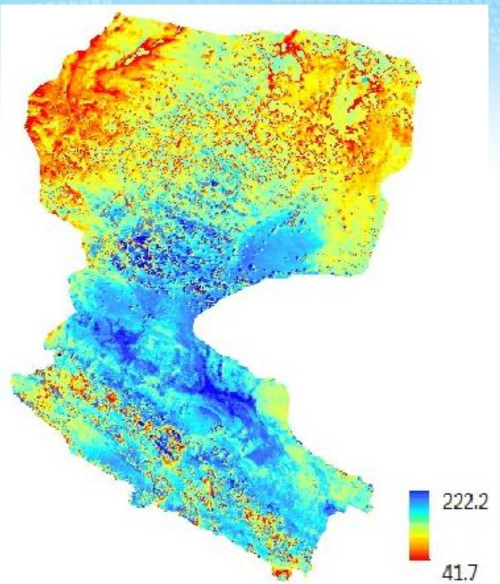
•*Shufu Liu. Research on land surface net radiation remote sensing estimation. University of Chinese Academy of Sciences. Ph.D Paper .2013*

Comparison between Rn Estimated and Observed

2008/07/06

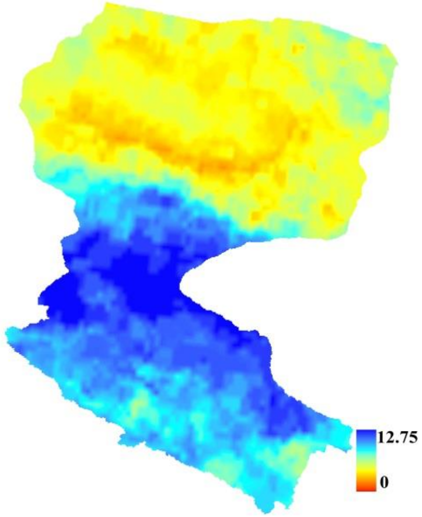


Sunshine Hour from Observation

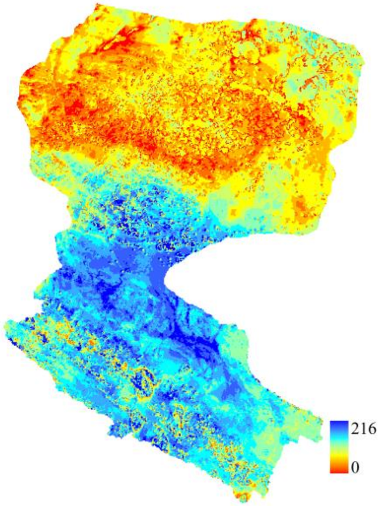


Surface Net radiation

2008/07/06



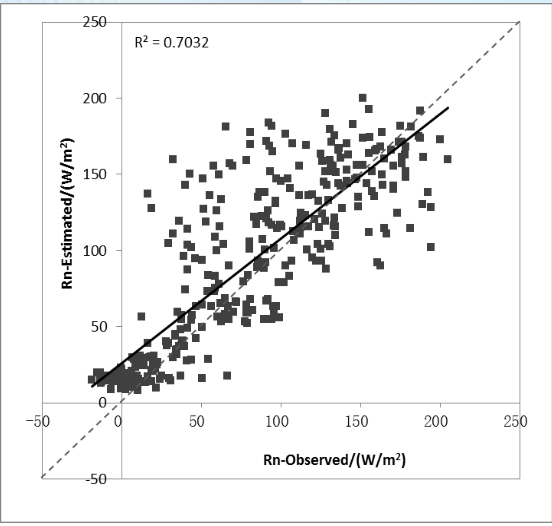
Sunshine Hour from FY-2D



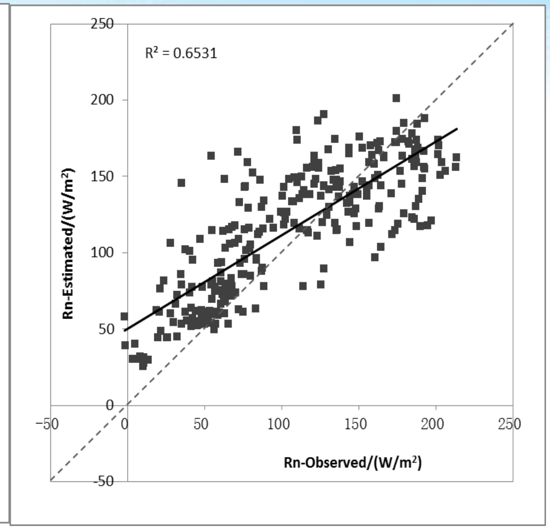
Surface Net radiation

•*Shufu Liu. Research on land surface net radiation remote sensing estimation. University of Chinese Academy of Sciences. Ph.D Paper.2013*

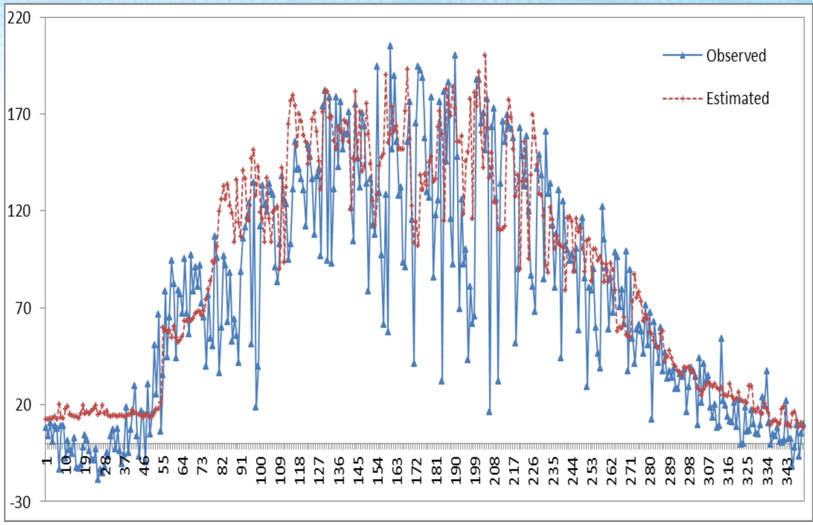
Comparison between Rn Estimated and Observed



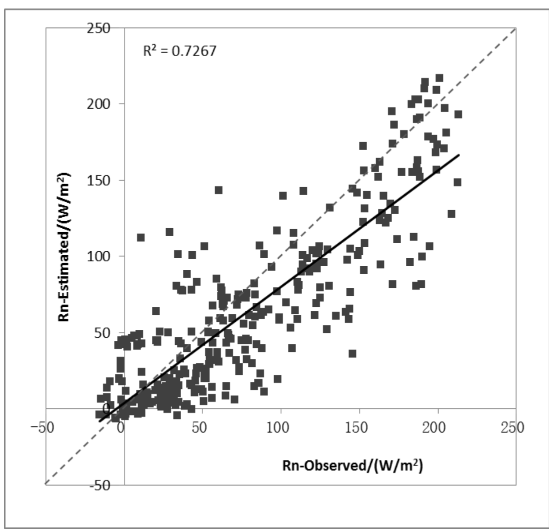
Arou



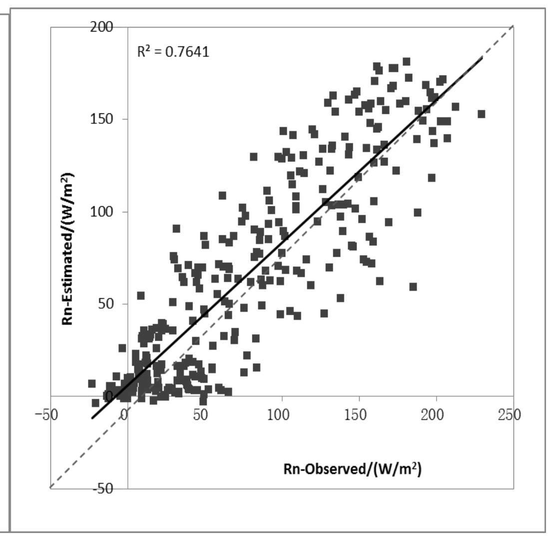
Linze



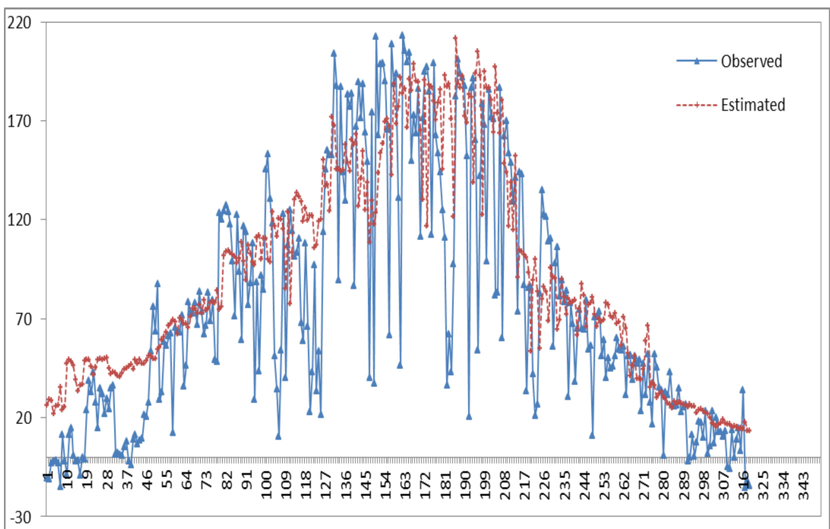
Arou



Yingke



Maliantan



Yingke

•Shufu Liu. Research on land surface net radiation remote sensing estimation. University of Chinese Academy of Sciences. Ph.D Paper.2013

Daily surface soil heat flux

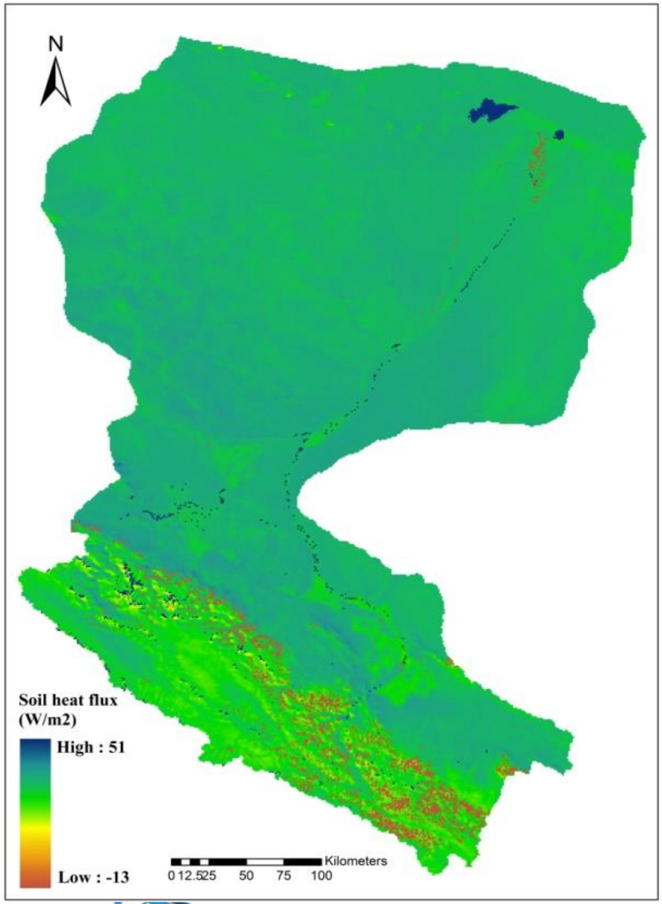
$$G(z,t)=D_0\frac{\partial}{\partial z}T(z,t)=D_0\frac{1}{\sqrt{D_0}}\frac{\partial^{(1/2)}}{\partial t^{(1/2)}}\left[T(z,t)-T_0\right]=\sqrt{\frac{D_0}{\pi}}\int_0^t\frac{dT(z,s)}{\sqrt{t-s}}G(t)=\frac{\Gamma}{\sqrt{\pi}}\int_0^t\frac{dT(s)}{\sqrt{t-s}}$$

$$\Gamma = f(\Delta\mathrm{T}, \mathrm{albedo}, \mathrm{S}_0, \omega, \delta, \mathrm{C}_\mathrm{r}, \phi)$$

$$G_0(\mathrm{t}) = G(0,t)$$

$$G_0 = \int G_0(t)$$

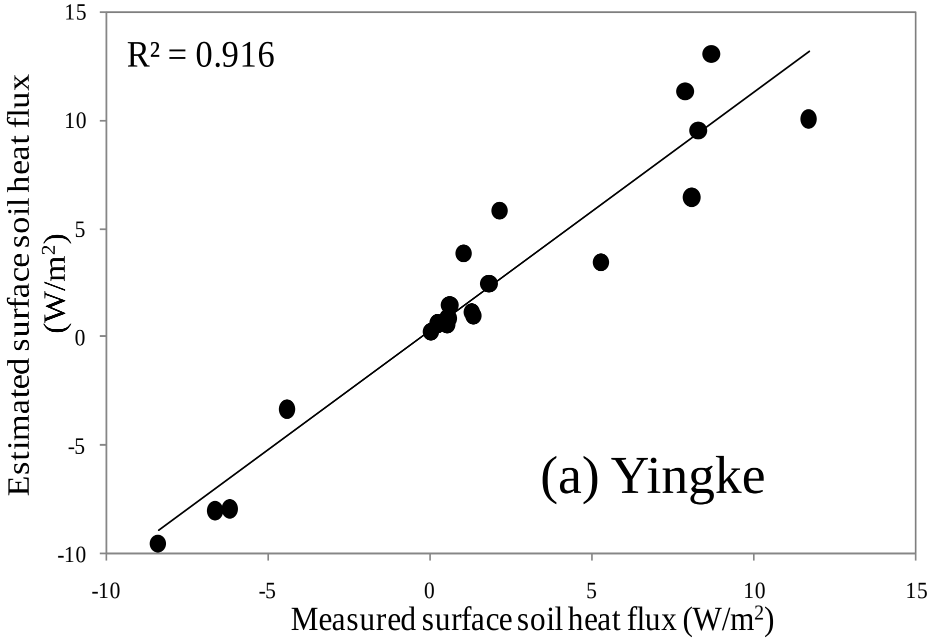
- ΔT: The maximum temperature difference between day and night (FY-2F).
- albedo: Surface albedo
- S_0: Solar constant
- C_r: Shortwave atmospheric transmittance
- ω: Angular velocity of earth rotation
- δ: Solar declination angle (in radians)
- ϕ: The local dimension (in radians)

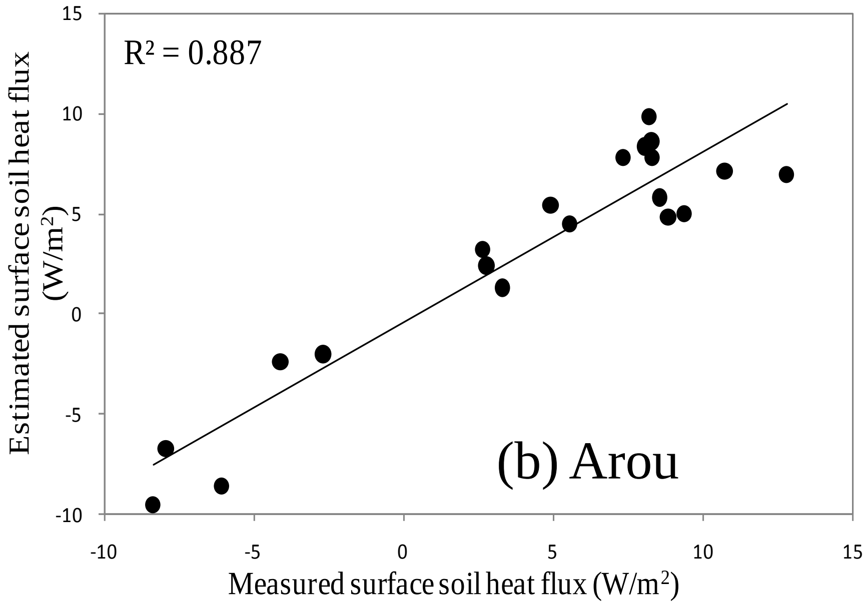


Dialy surface soil heat flux on the Aug. 22th,2008

•*Weiwei Zhu, Bingfang Wu, Nana Yan, Xueliang, Feng, Qiang Xing. A method to estimate diurnal surface soil heat flux from MODIS data for a sparse vegetation and bare soil. Journal of Hydrology, 511(2014)139-150.*

Comparison between daily G_0 Estimated and Observed





Comparison of the observed and estimated soil heat flux : (a) Yingke station, (b) Arou station

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• *Weiwei Zhu. Research on land surface soil heat flux remote sensing estimation. University of Chinese Academy of Sciences. Ph.D Paper .2014*

Modelling of aerodynamic roughness length

Aerodynamic Roughness

Vegetation
（NDVI）

Thermal Factor
Surface Temperature

Dynamic factor
Doppler Wind profile

Topography factor
ASTER GDEM-30

Surface roughness
SAR

Source Area		
Topography	Vegetation	Surface Elements

Wind velocity	Temperature gradient
Dynamic factor	Thermal Factor

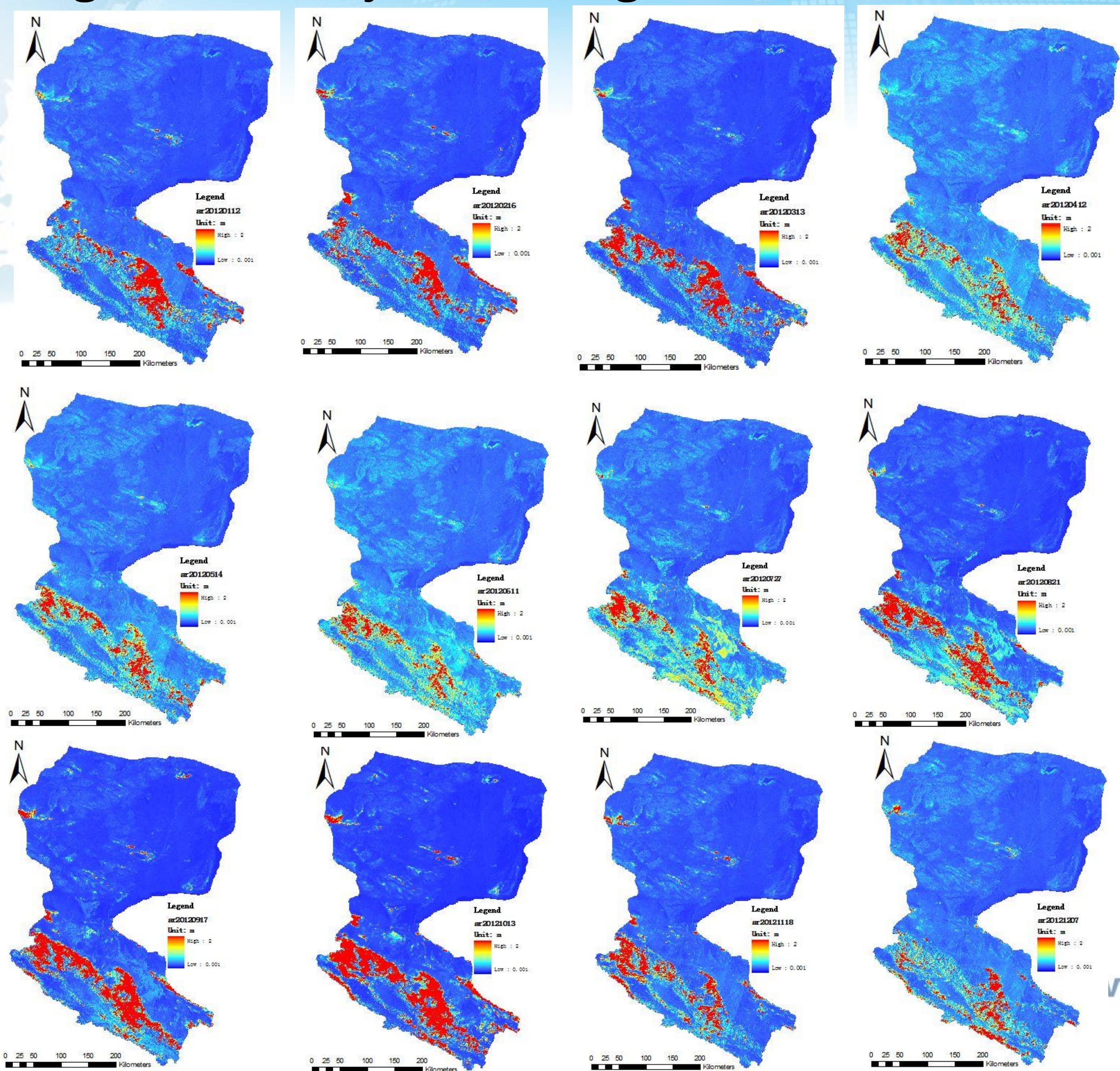
Geometric roughness at pixel

Dynamic overlap

Aerodynamic Roughness

Ground measurement

Integrated Aerodynamic roughness for time series in 2012

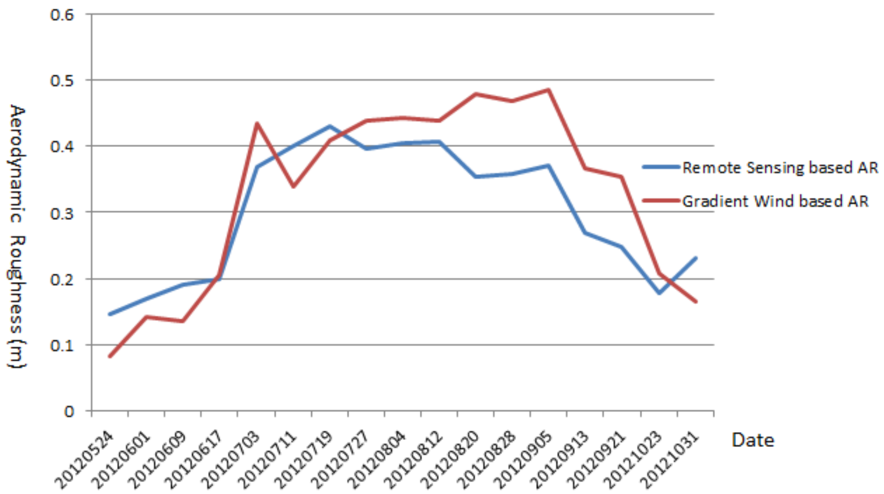


Jan. to Apr.

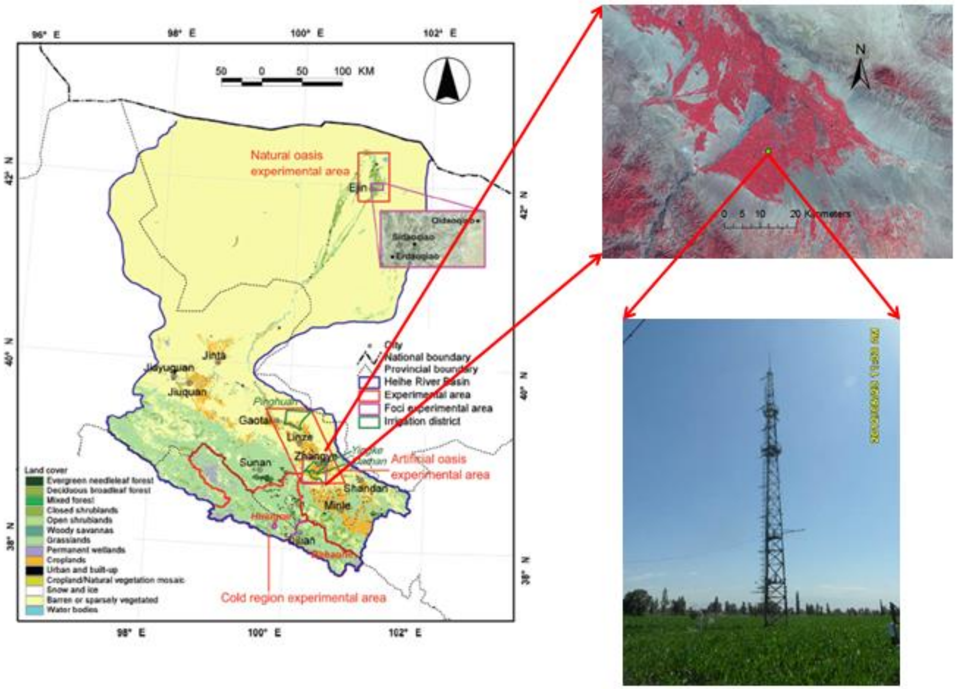
May. to Aug.

Sep. to Dec.

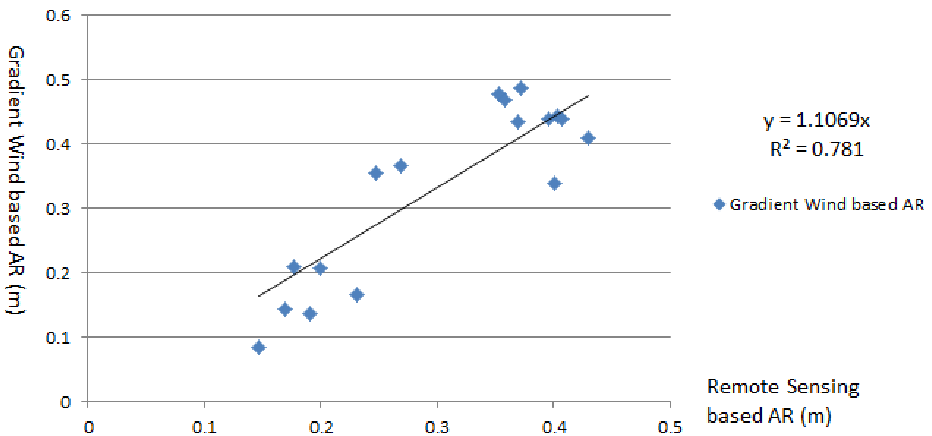
Validation of the Integrated Aerodynamic roughness on the farmland



Change trend comparison between wind gradient and remote sensing based aerodynamic roughness



Validation site



Scatter chart between wind gradient and remote sensing based aerodynamic roughness

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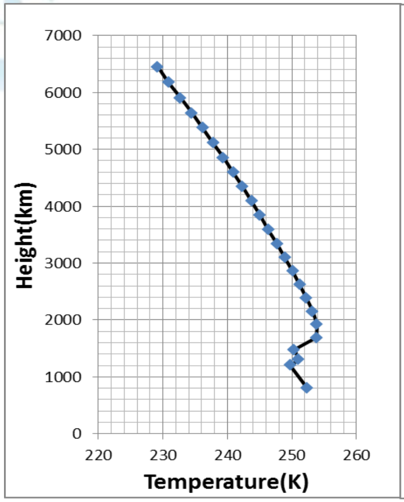
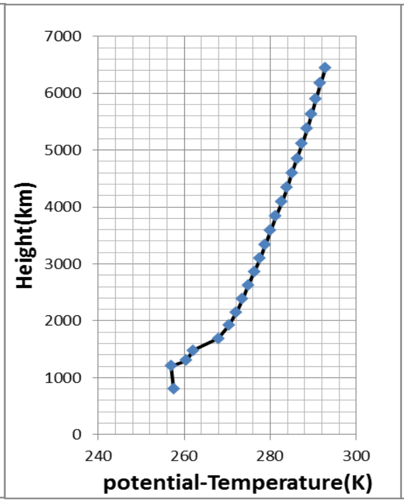
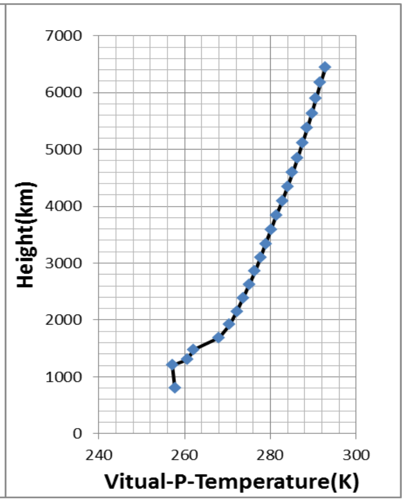
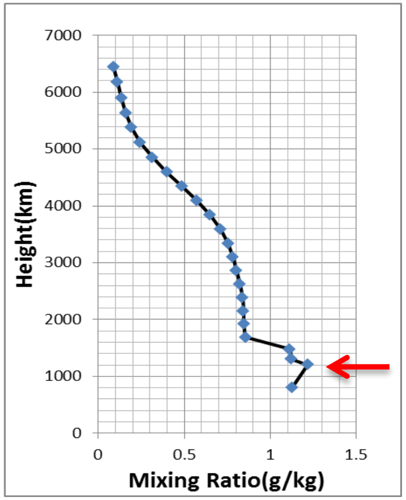
ABL (Atmospheric Boundary Layer)

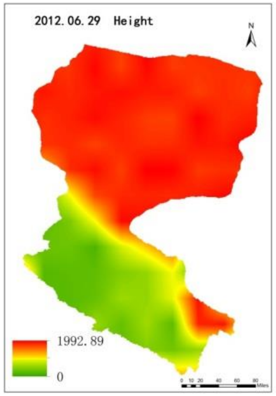
- With this method, we can reduce the sensitivity of ETwatch to the thermal character of ground. Using the atmospheric profile data derived from remote sensing, we can estimate the spatial distributing of MH, then improve the accuracy of ET model .

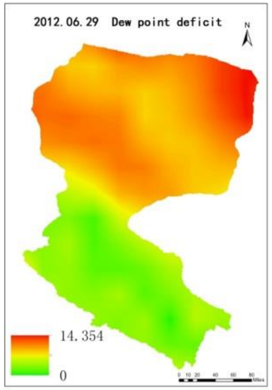


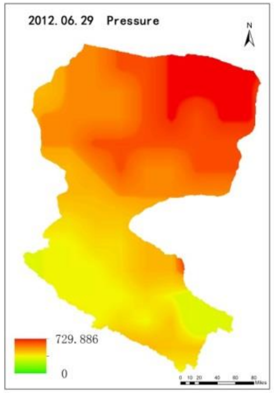


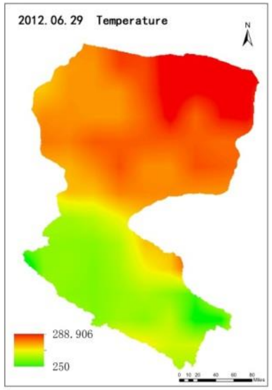






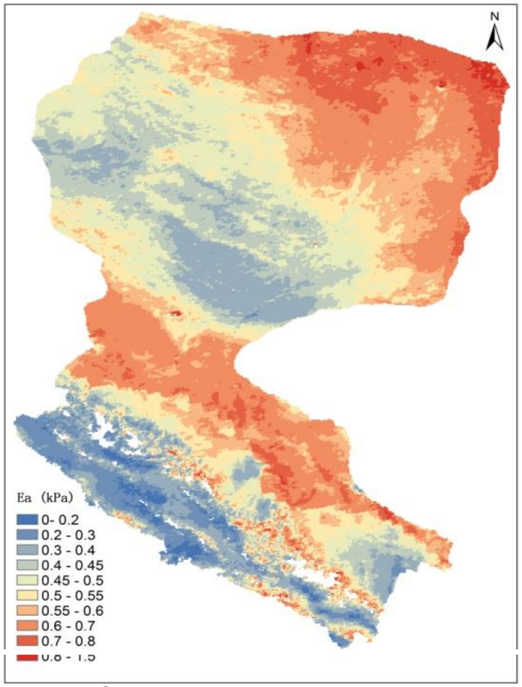




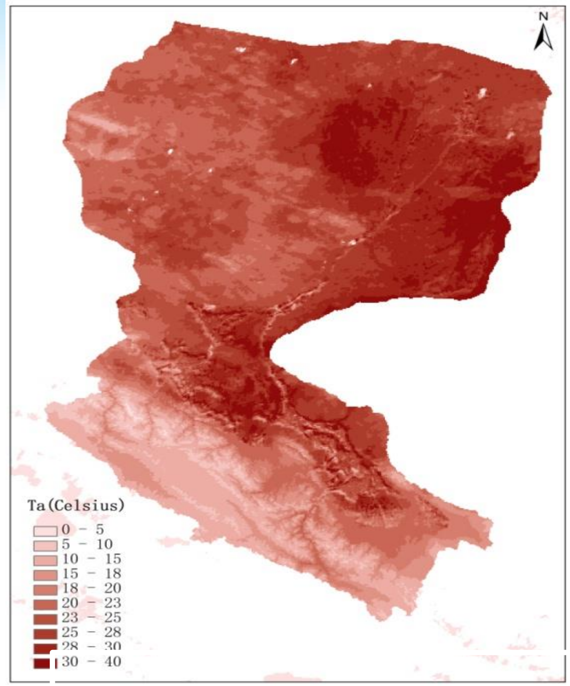


•*Xueliang Feng, Bingfang Wu, Nana Yan, Weiwei Zhu. Method to derived mixed boundary layer height from MODIS atmospheric profile data product at Heihe river basin. Atmosphere 2015, 6, 1346-1361; doi:10.3390/atmos6091346*

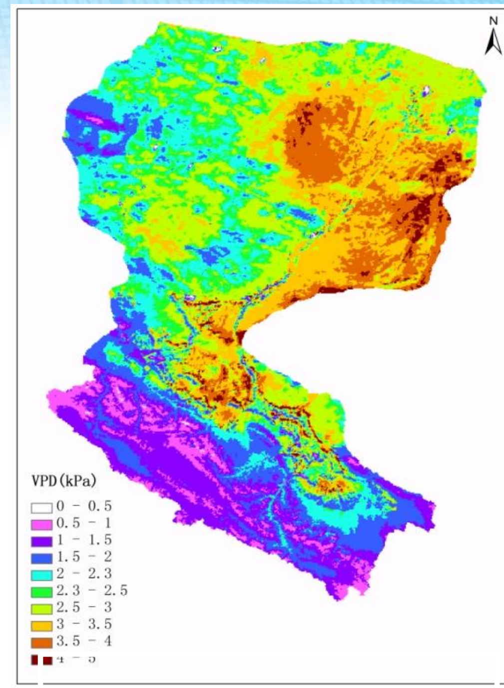
Vapor pressure deficit



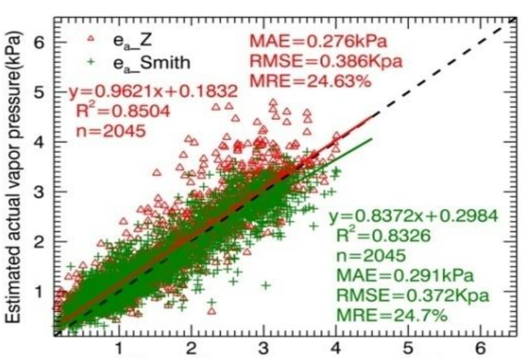
Near-surface actual vapor pressure

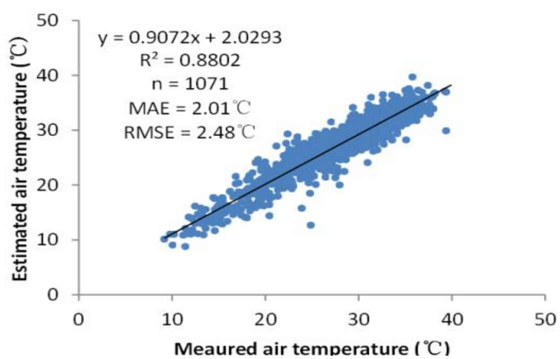


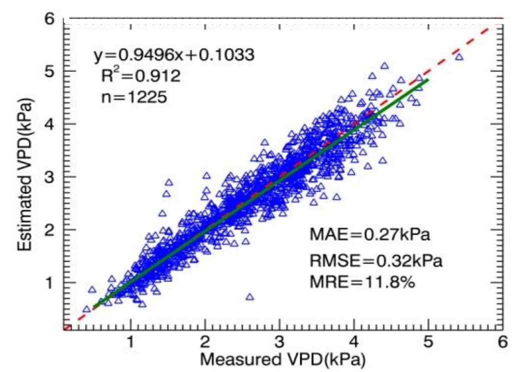
Near-surface air temperature



Vapor pressure deficit







From Aqua observation data in the Heihe River Basin at 05.55 UTC on 3 September 2012

• *Hongmei Zhong, Bingfang Wu, Nana Yan, Weiwei Zhu, Xueliang Feng. An improved satellite-based apporach for estimating vapor pressure deficit from MODIS data. Journal of Geophysical Research: Atmospheres. 119, 12256-12271, doi: 10.1002/2014JD022118..*

Sensible heat flux

$$\left\{\begin{aligned}
&R_{ae} = R_s \cdot (e_s - e_a) / (e_s^* - e_s) \\
&R_s = f_c \cdot R_c + (1 - f_c) \cdot R_{soil} \\
&R_c = \frac{r_{c\min}}{LAI} \cdot F_1^{-1} \cdot F_2^{-1} \cdot F_3^{-1} \cdot F_4^{-4} \\
&R_{soil} = \exp(a - b(SM / SM_{wilt})) \\
&e_s = \Omega \cdot h_{s,\max} \cdot e_s^* + (1 - \Omega) \cdot e_a \\
&\Omega = (\Delta + \gamma) / [\Delta + \gamma \cdot (1 + R_s / R_a)]
\end{aligned}\right.$$

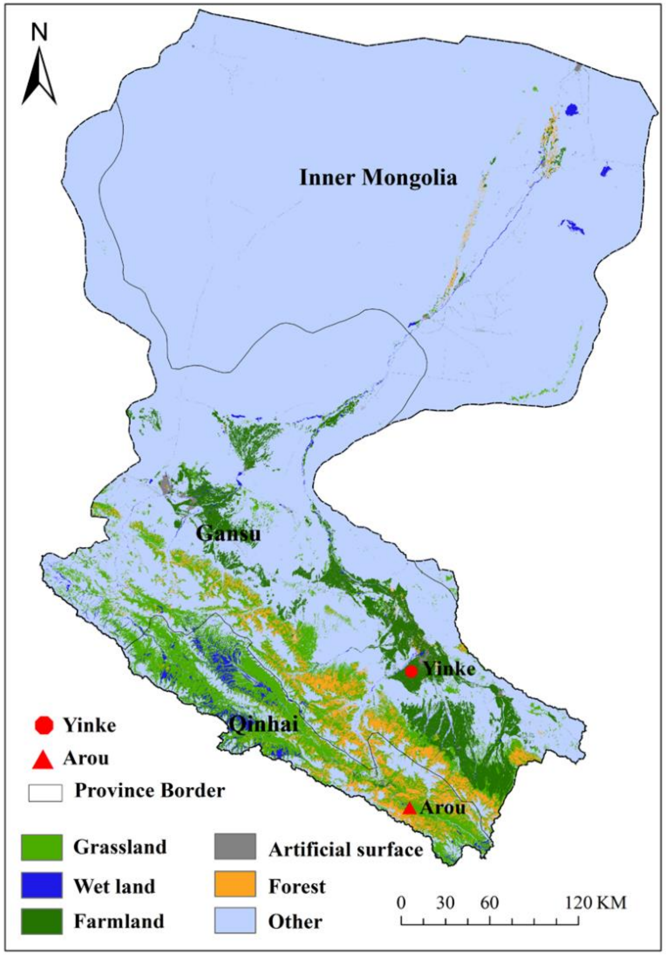
$$\Rightarrow \quad H = \frac{\rho \cdot C_p \cdot (T_s - T_a) \cdot (e_s^* - e_s)}{(e_s - e_a) \cdot R_s}$$

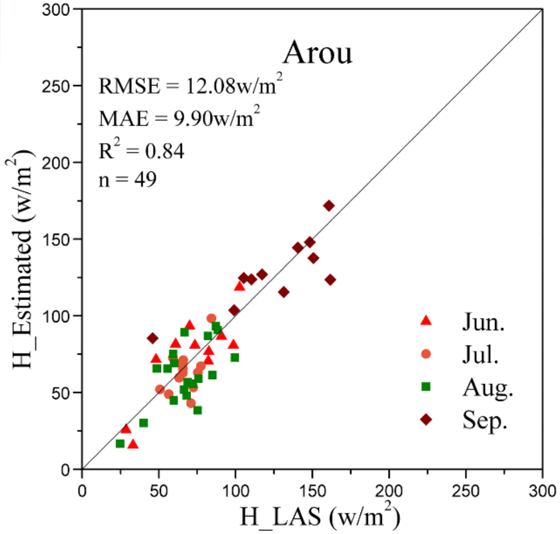
- Without involving the radiometric KB^{-1}
- Take the influence of environmental factors into account
- T_a and e_a are from PBL products
- Multiple remote sensing products are applied in this parameterization
- With a total Richardson number for stability correction, the iteration process is avoided.

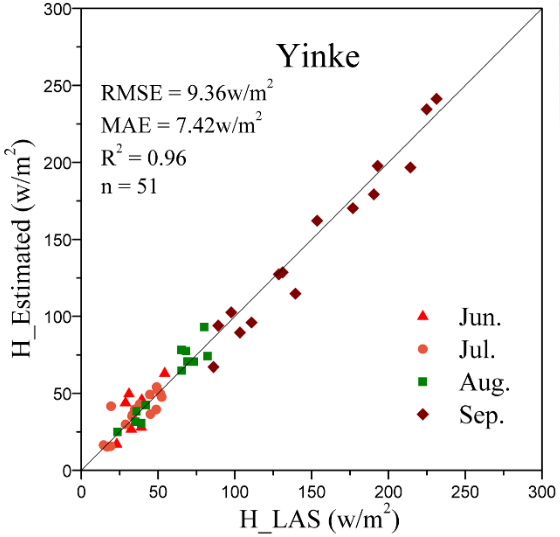
- R_{ae} : aerodynamic roughness to heat transfer
- R_s: surface resistance (soil and canopy)
- e_a: actual vapor pressure at reference height
- e_s: surface actual vapor pressure
- $e_s{}^*$: surface statured vapor pressure
- SM: soil moisture
- F_1: photosynthetically active radiation factor
- F_2: canopy water stress factor
- F_3: canopy vapor pressure deficit factor
- F_4: canopy air temperature factor
- R_a: aerodynamic resistance to momentum

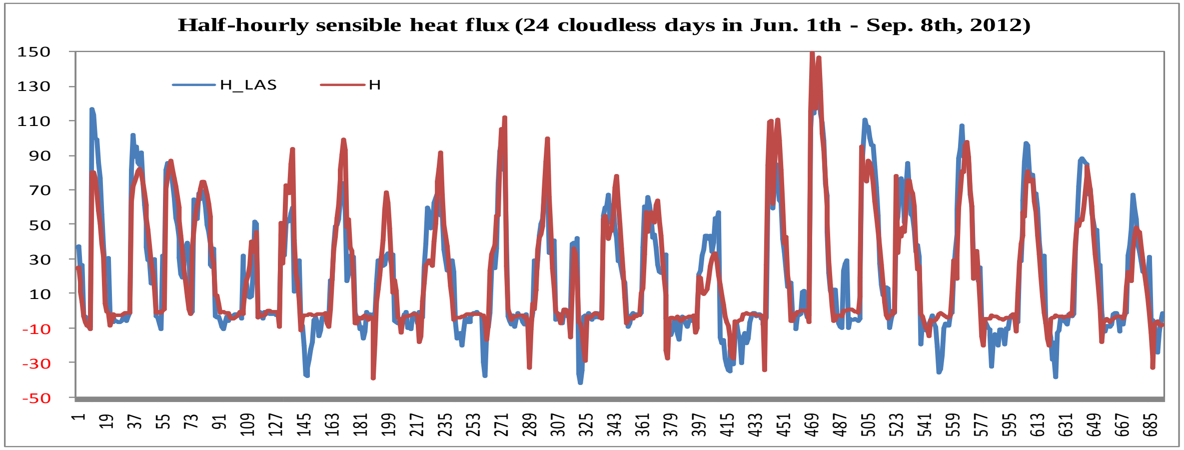
•Qifeng Zhuang, Bingfang Wu, Nana Yan, Weiwei Zhu, Qiang Xing. A method for sensible heat flux model parameterization based on radiometric surface temperature and environmental factors without involving the parameter KB-1, International Journal of Applied Earth Observation and Geoinformation.

Sensible heat flux





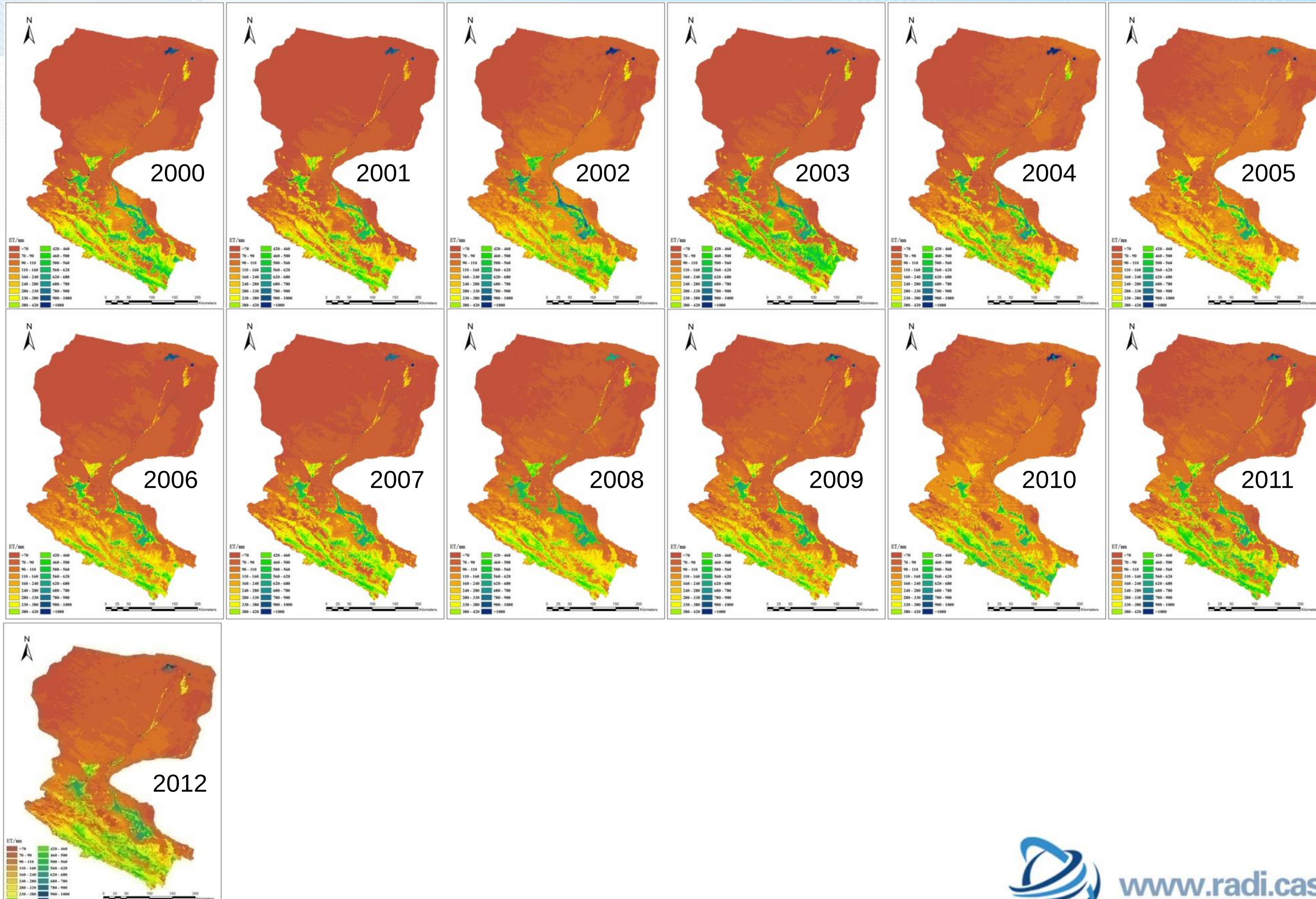




Validation with LAS measured sensible heat flux over crop and grassland in Heihe River basin, China.

• *Qifeng Zhuang, Bingfang Wu, Nana Yan, Weiwei Zhu, Qiang Xing. A method for sensible heat flux model parameterization based on radiometric surface temperature and environmental factors without involving the parameter KB-1, International Journal of Applied Earth Observation and Geoinformation.*

Heihe River basin 1km ET dataset



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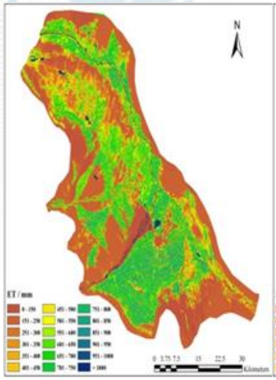
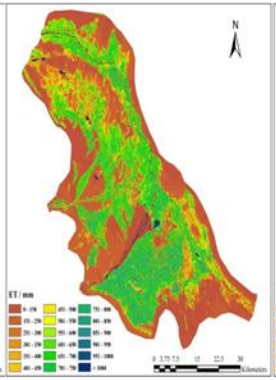
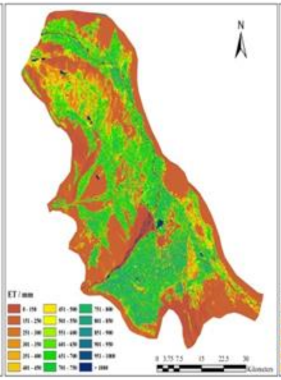
The oasis in the middle reaches of Heihe River Basin 30m ET dataset


2000


2001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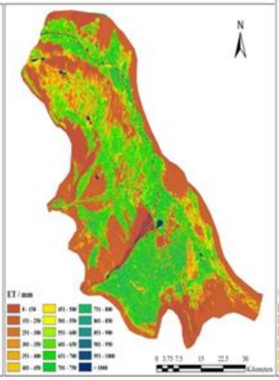
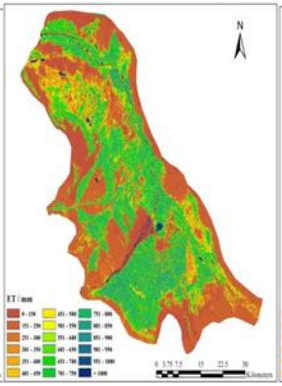
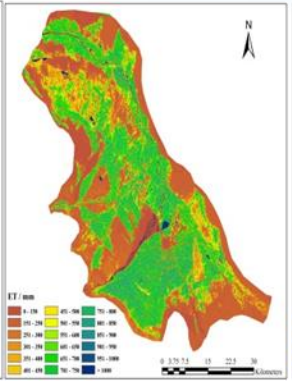
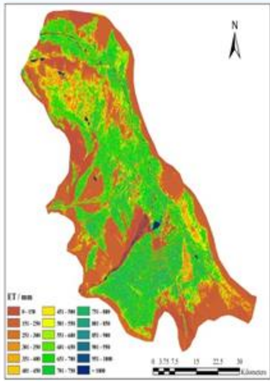
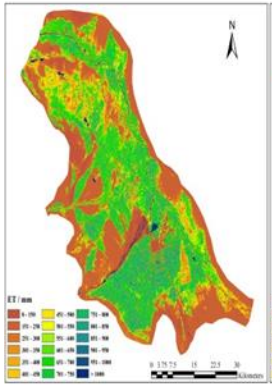
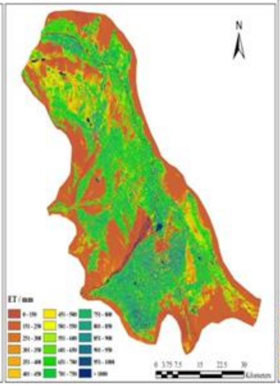

2003

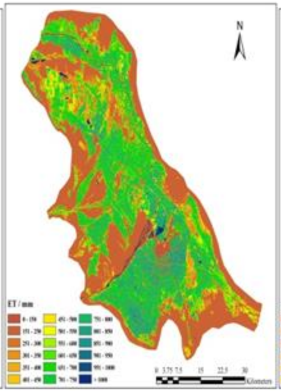

2004

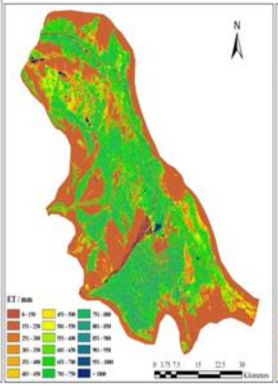

2005


2006


2007


2008


2009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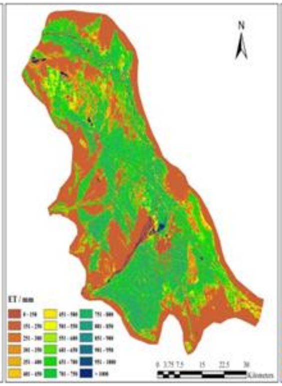
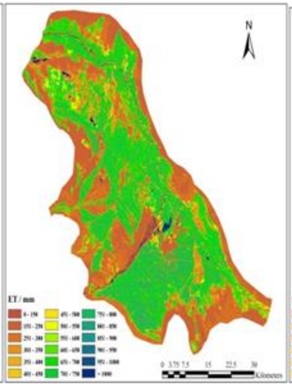
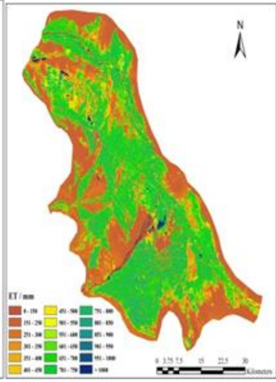
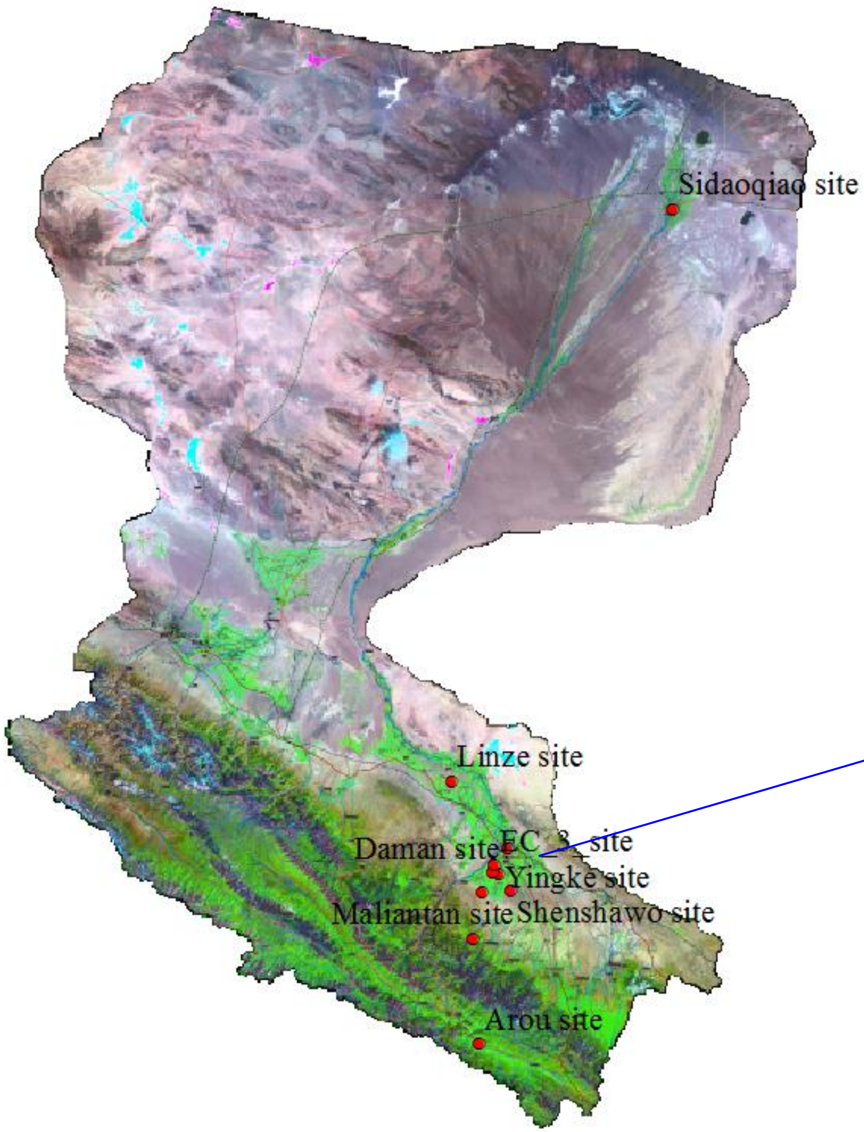

2011

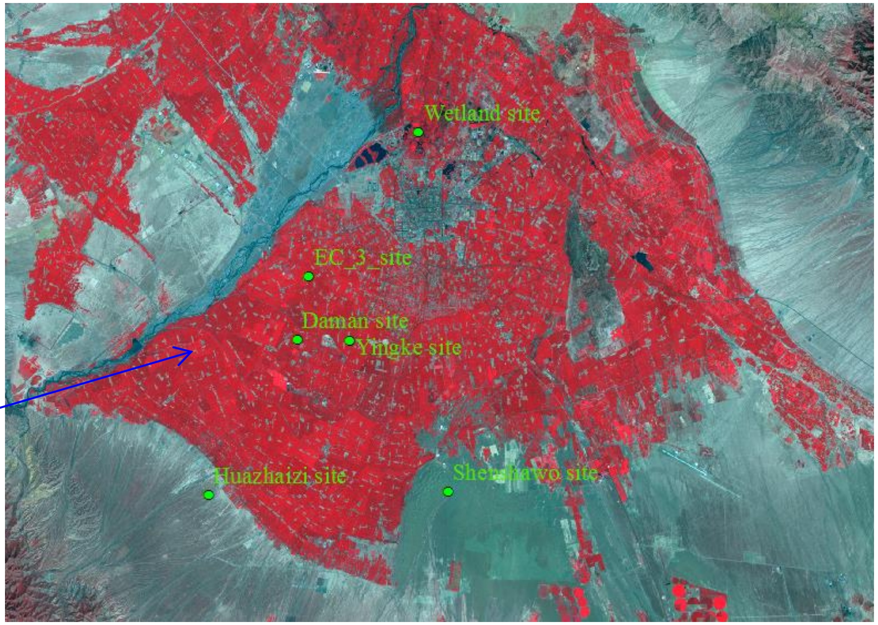

2012


2013

Validation

Validation sites in the Heihe River basin





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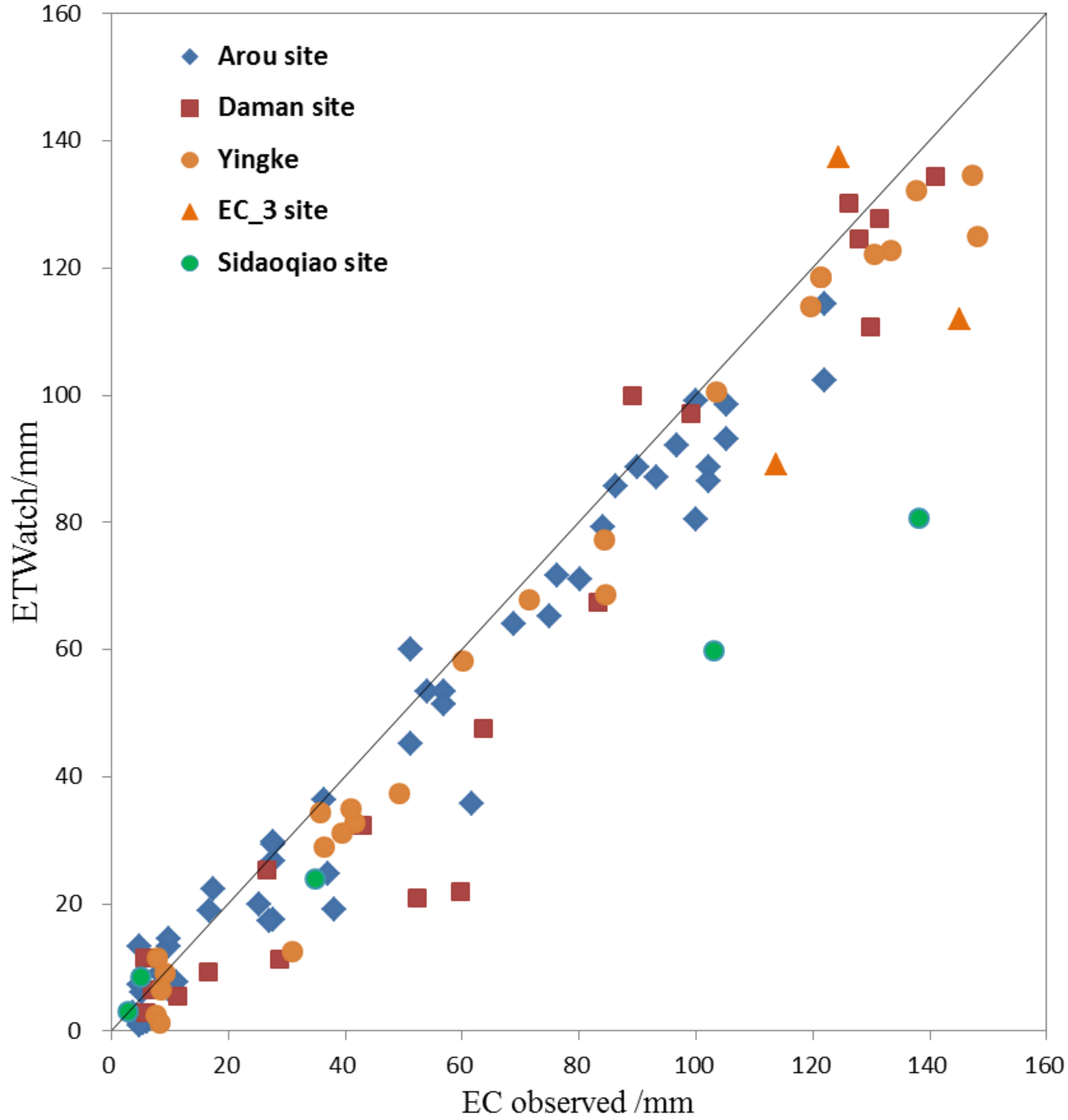
Validation results in the Heihe River basin

Overall verification results in the upstream, middle reaches and downstream



RMSE : 1.300mm;
MRE : -11.827%;
MAPE : 14.517%;
R : 0.97

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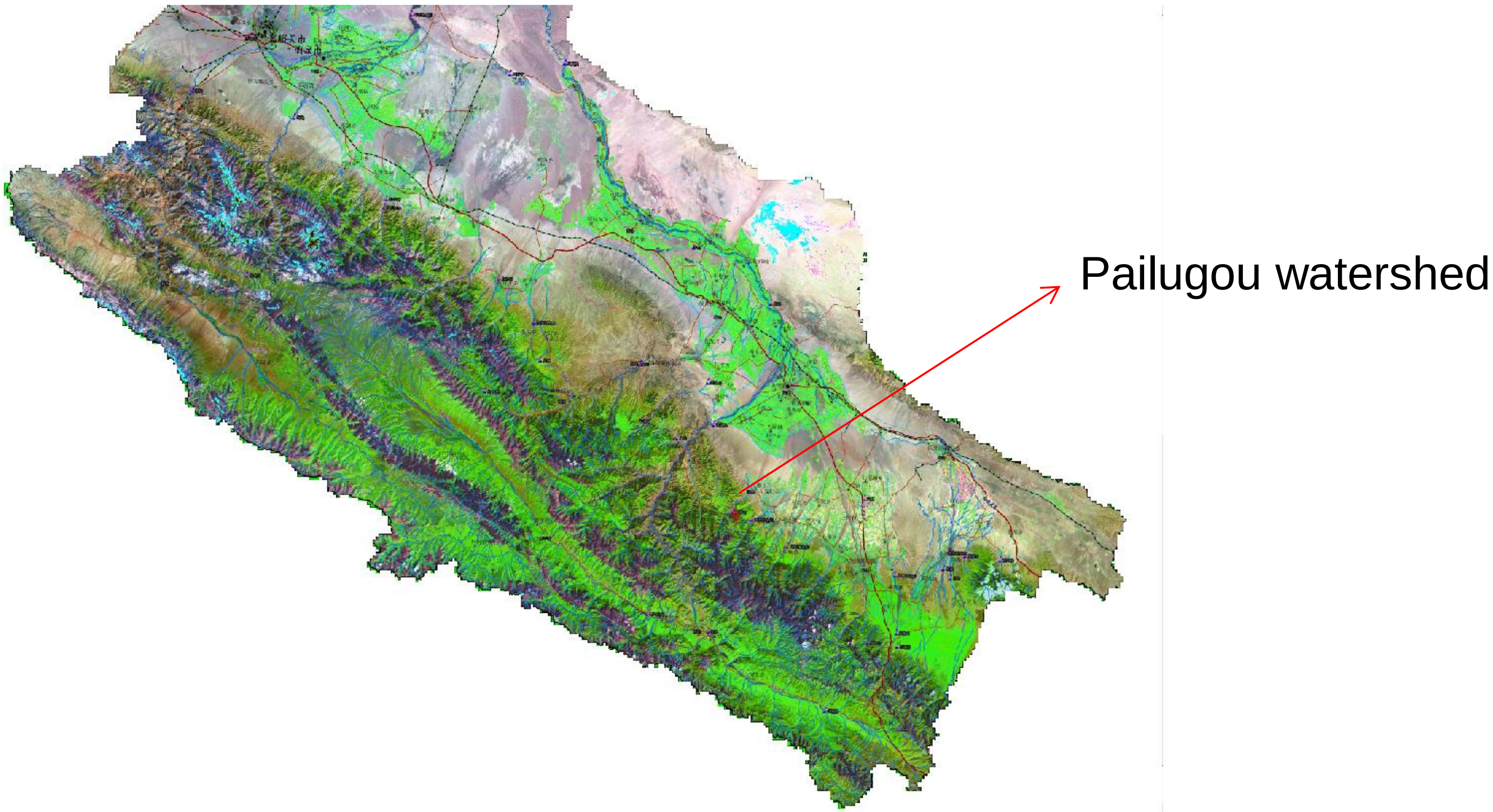
Validation results in the Heihe River basin

Validation results of water balance in Pailugou watershed of 2012-2013



	Area (km^2)	Rainfall (mm yr^{-1})	Runoff (mm yr^{-1})	Water balance ET (mm yr^{-1})	ETWATCH (mm yr^{-1})	Deviation (%)
Pailugou watershed	2.89	458.59	62.83	395.76	437.00	9.44

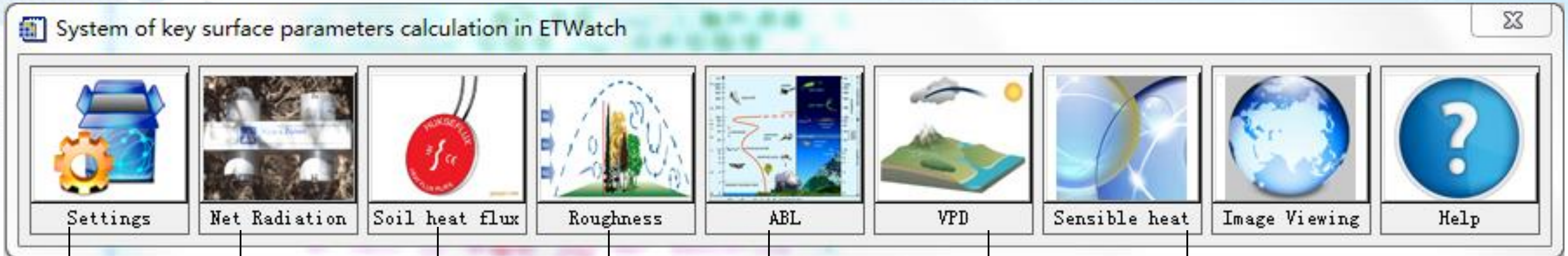
Validation results in the Heihe River basin

Validation results of water balance in Heihe River Basin

Year	Rainfall ($mm\ yr^{-1}$)	Runoff ($mm\ yr^{-1}$)	Water balance ET ($mm\ yr^{-1}$)	ETWATCH ($mm\ yr^{-1}$)	Deviation (%)
2001	95.7	9.1	86.6	106	-18%
2002	120.4	11.3	109.2	128	-15%
2003	138.5	13.3	125.2	128	-2%
2004	102.7	10.5	92.1	125	-26%
2005	126.5	12.7	113.8	120	-5%
2006	108.7	12.7	96.0	115	-16%
2007	163.7	14.6	149.2	119	25%
2008	129.4	13.6	115.8	128	-10%
2009	125.3	14.6	110.6	121	-9%
Average	123.4	12.5	110.9	121.1	-8%

Operational system

ETWatch system



Preference

Atmospheric Boundary Layer

Soil heat flux

Vapor pressure deficit

Net Radiation

Sensible heat flux

Aerodynamic roughness length

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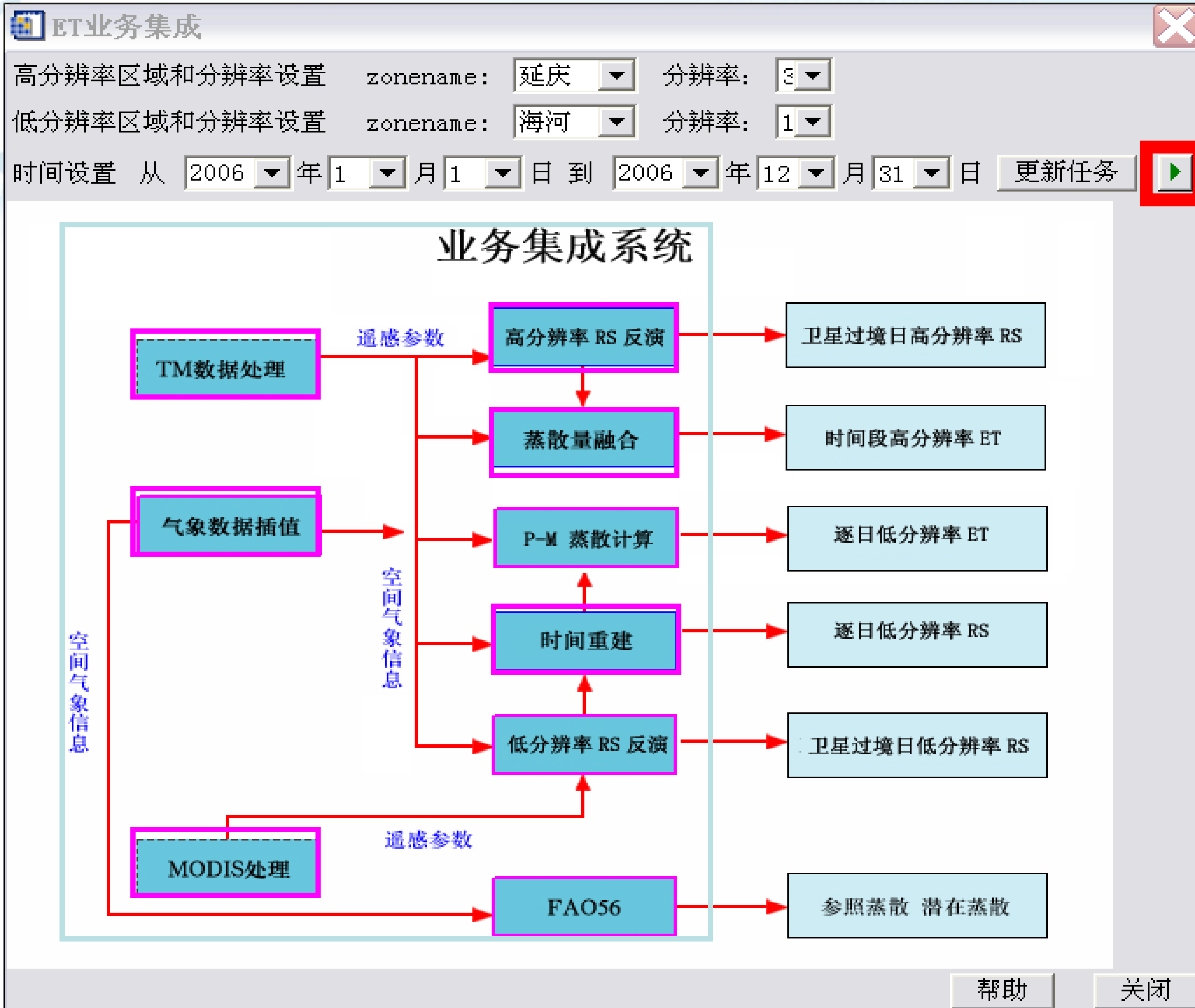
Running entire ETWatch in single window

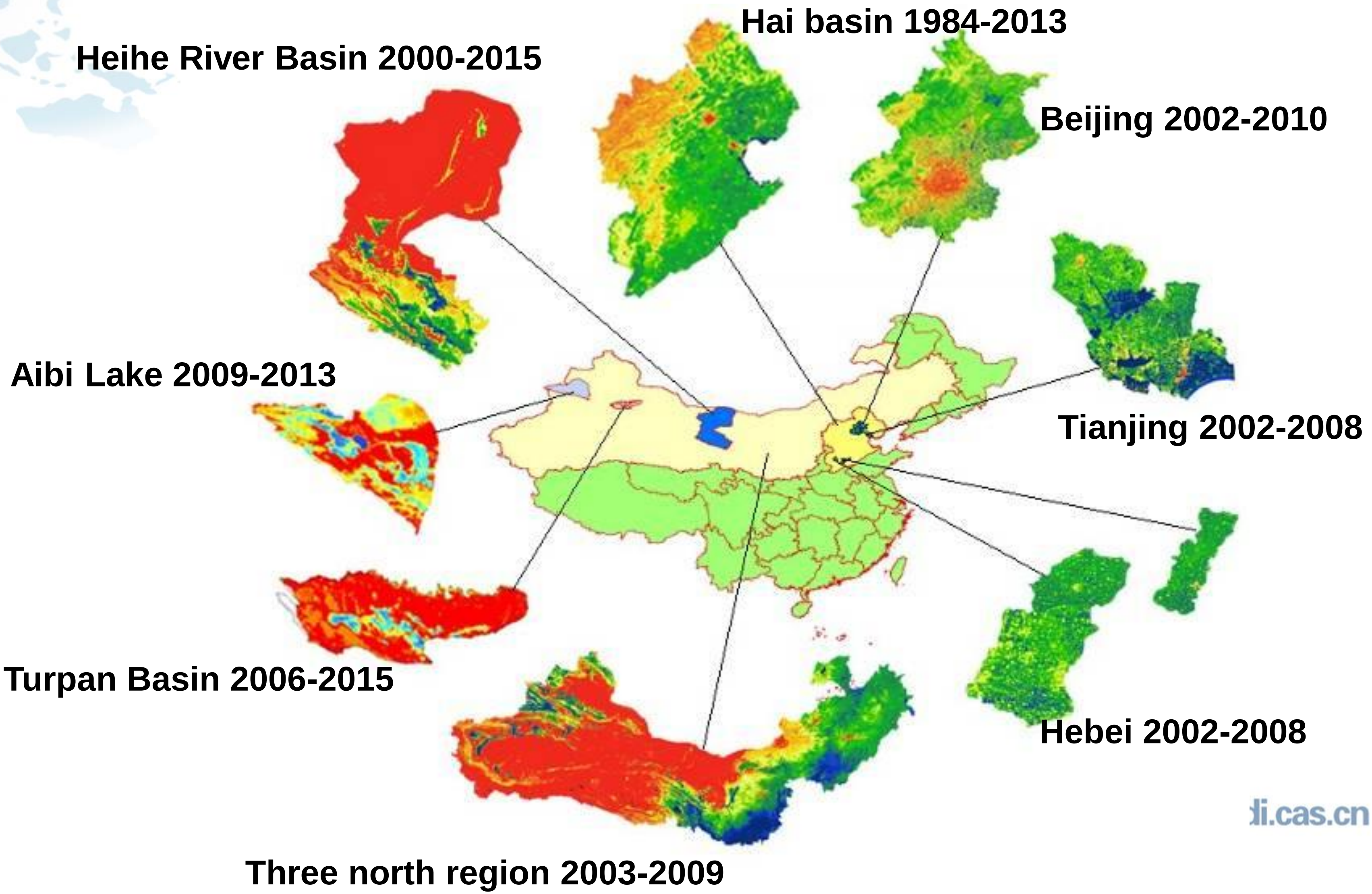


ETWatch Features

- Basin-wide (mountain, urban and rural),
- Daily products, 5m to 1km resolution
- Parameterized model
- Systematic and operational,
  - Hai Basin commission
  - Beijing water affair office.
  - Turpan Water Bureau to be installed
- Pre-processing of all data used
- Internal calibration
- Quality Control in process

Application

Application: ETWatch in China



Objective to use ET

1. Hai Basin (GEF & CAS): **planning, allocation and water productivity**
2. Siyang River (MWR): **Supervision** on water consumption
3. Three North Reforestation (CAS): **Groundwater depletion and stress**
4. North China (MEP): Ecological restoration and **ecosystem services**
5. Heihe River (NSF): **Method development and validation**
6. Miyun reservoir (NSF): Method development **on mountain area**
7. Loess Plateau (MOST): Ecological restoration impact on **water yield**
8. Cropland (MOST) **: Field level** crop biomass and carbon fluxes
9. Sustainable Agriculture (CAS): **Crop productivity**

1. Aibi Lake Basin (GEF): planning and **target ET**
2. Turpan (WB): planning, allocation, target ET and supervision

Support Project

Over 15 Millions CNY from Chinese Funds

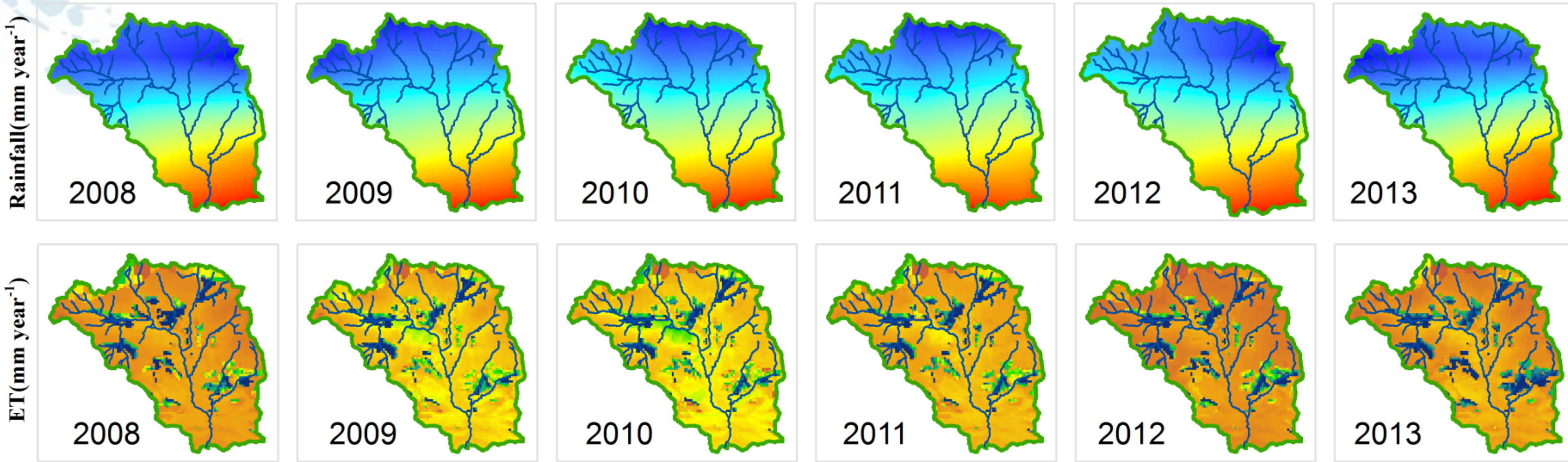
1. National Natural Science Foundation: Method to quantify Aero dynamic roughness [2013-2016]
2. National Natural Science Foundation: Parameterization of ET estimation in Arid Area [2011-2014]
3. Special Programme from Chinese Academy of Sciences: Status, speed, mechanism and potential of carbon storage in ecosystem (2010-2015)
4. Ministry of Environment Protection: China ecological Change Detection with Remote Sensing for 2000-2010 (2012-2014)
5. China Fundamental Research (973: Regional Ecosystem Service Assessment at Loess Plateau (2009-2013)
6. China High Technology Research (863) : Field level crop biomass and carbon fluxes estimation (2009-2011)
7. Knowledge Innovation Program of the Chinese Academy of Sciences, Post Environmental Impact Assessment for Hai Basin and three north reforestration area (2007-2010):
8. Knowledge Innovation Program of the Chinese Academy of Sciences, Better Land Resources Management for Sustainable Agriculture (2007-2010): Crop productivity

1. World Bank/GEF consultancy project: ET estimation with remote sensing and application in Aibi Lake Basin (2013-2016)
2. World Bank Consultancy project: ET estimation with remote sensing and application in Turpan (2008-2015)

Watershed ET Management

Estimation of WCA

Water Consumption Amount (WCA) = Average rainfall (P) – Average nature ET



Name	Area(km^2)	Item	Rainfall, Natural ET, and WCA (Unit: mm)							Rainfall, Natural ET, and WCA (Unit:10^6m^3)						
			2008	2009	2010	2011	2012	2013	AVE.	2008	2009	2010	2011	2012	2013	AVE.
Etanggou	342	P	351	360	195	155	319	411	298	120	123	67	53	109	141	102
	342	Nature ET	42	52	28	32	43	65	44	14	18	10	11	15	22	15
	342	WCA	309	307	167	123	276	346	255	106	105	57	42	94	118	87

Conclusion: WCA at Etanggou is 87×10^6 m^3· year^{-1}

How much water can be consumed by agriculture(WCA_A)

$WCA_A = WCA_H – WCA_{indus} - WCA_{bio}$

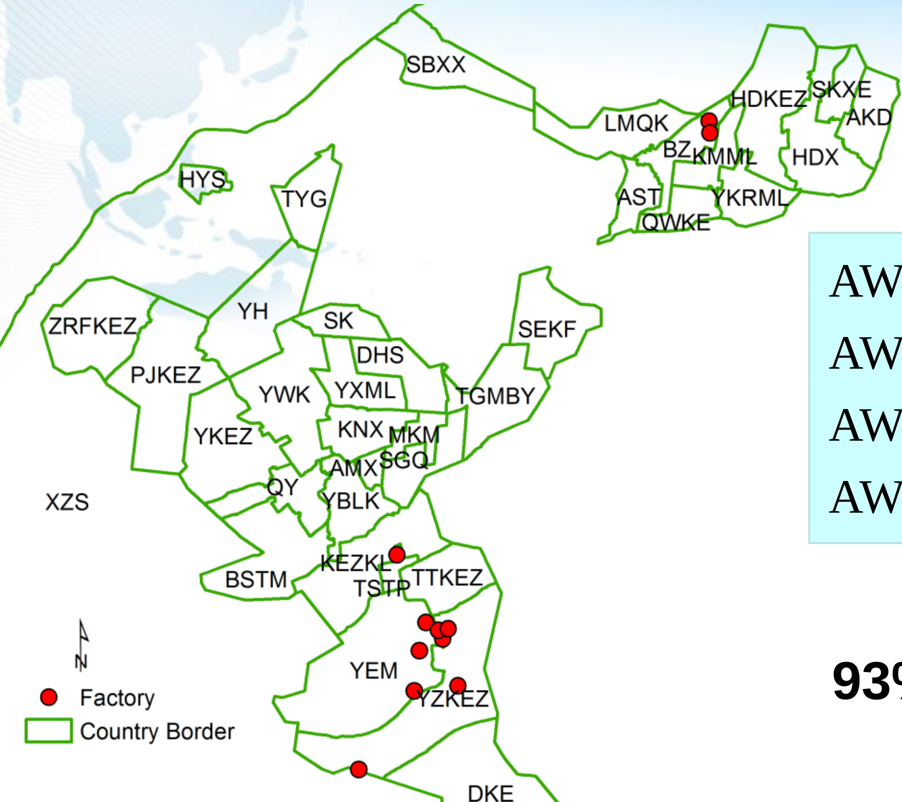
WCA_{bio}= WCAbio_c*(1+GR_{bio})*(Year - CurrentYear)

WCA_{Indus}= WCA_{Indus_c}*(1+GR_{Indus})*(Year - CurrentYear)

Year	$WCA_H(10^6m^3)$	$WCA_{indus}(10^6m^3)$	$WCA_{bio}(10^6m^3)$	$WCA_A(10^6m^3)$
CurrentYear	87	2.04	2.15	82.81
2020	87	5.6	2.35	79.05

GR_{bio} : according to the population plan, the growing rate would be controlled below 1.15%
GR_{indus}: according to the industrial developing plan at Etanggou, 3 million cubic water will be transferred to a iron and steel factory (in the south of Turpan) from Ertanggou region, besides, 1.2 million cubic water will be allocated to petroleum exploitation in 2020.

Actual Agricultural Water Consumption at Ertanggou



$AWC_{AG} = AWC_{Total} - AWC_{RAIN}$

AWC_{AG} : Water consumption by irrigation

AWC_{Total} : Total water consumption from cropland

AWC_{RAIN} : Water consumption by rainfall

93% more than allowed

Items	2008	2009	2010	2011	2012	2013	Average
$AWC_{Total}(10^6m^3)$	166.7	157.6	142.5	165.6	162.7	192.8	164.6
$AWC_{RAIN}(10^6m^3)$	9.9	3.2	11.9	4.4	6.6	6.3	7.0
$AWC_{AG}(10^6m^3)$	157	154	131	161.2	156	187	158

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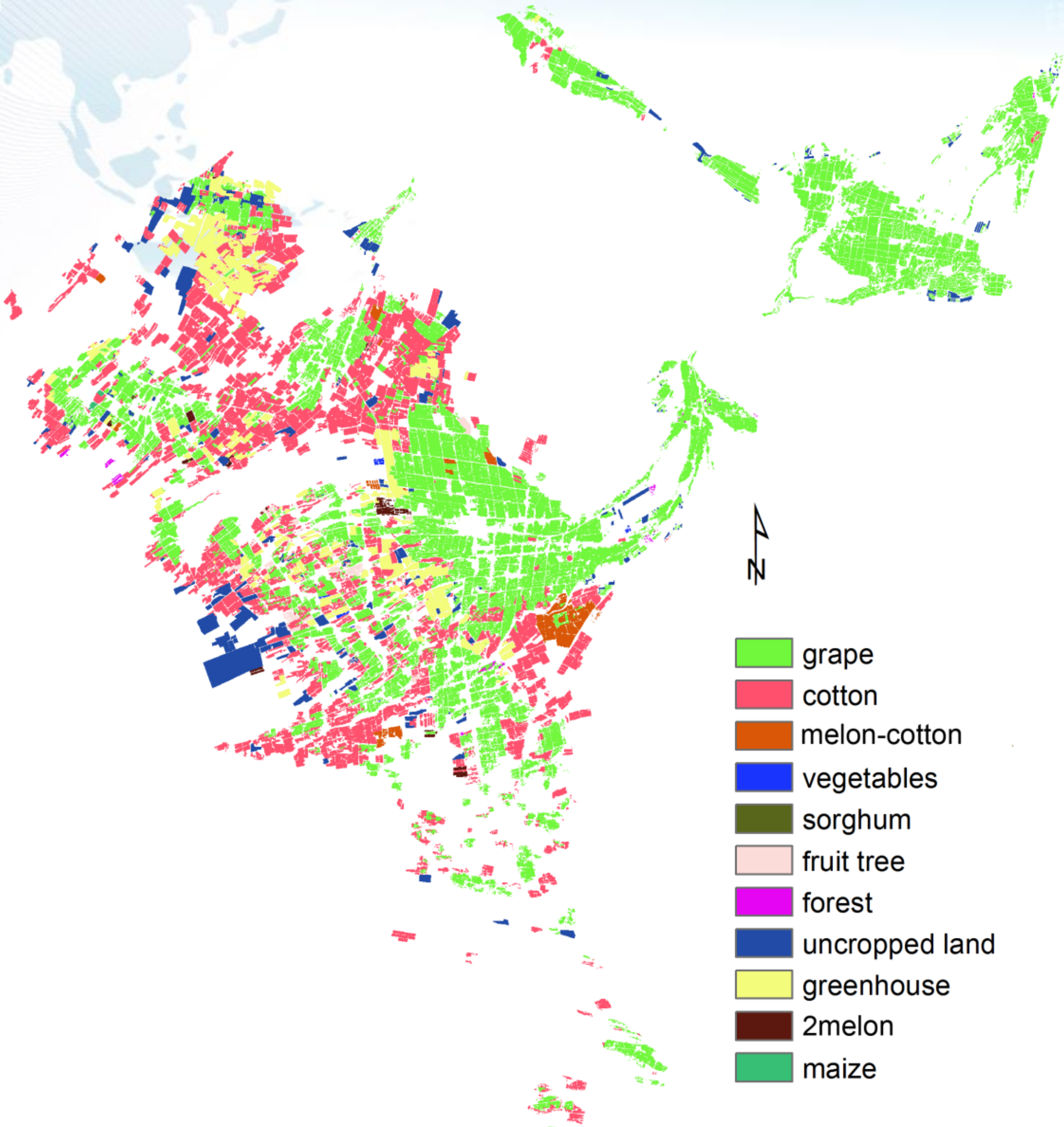
Maximum allowed Cropland



Crop	Average ET	Fraction
Grape	851	58.48%
Cotton	584	26.88%
Melon-Cotton	610	0.73%
Two Melons	679	0.06%
Others	577	0.23%
Average	661	

$$ETcrop = \sum_{i=1}^{N} Frac_i * ET_i$$

If the crop structure no change in Etanggou, the maximum cropland area is **189.3*10^3 in 2013 and 179.4*10^3 in 2020.**

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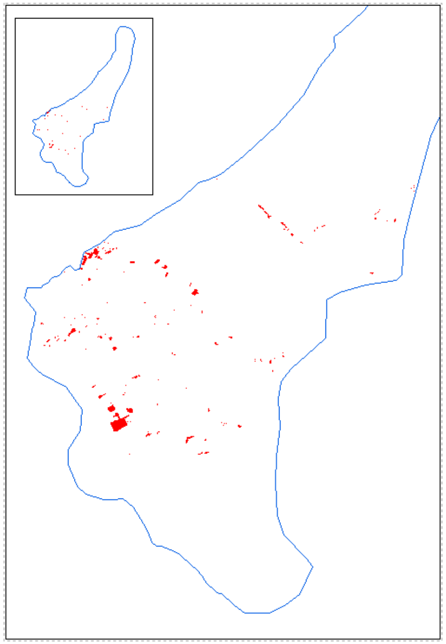
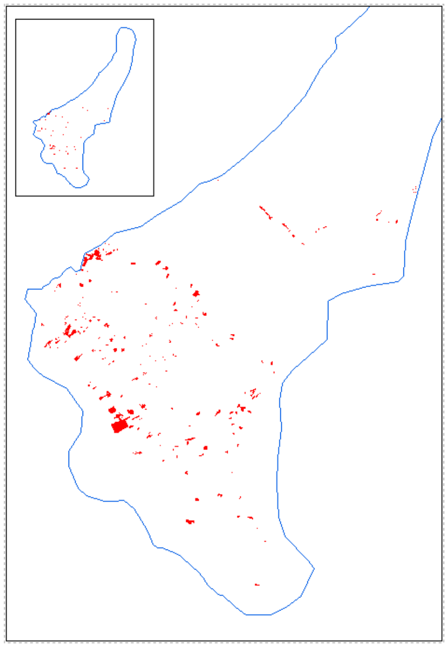
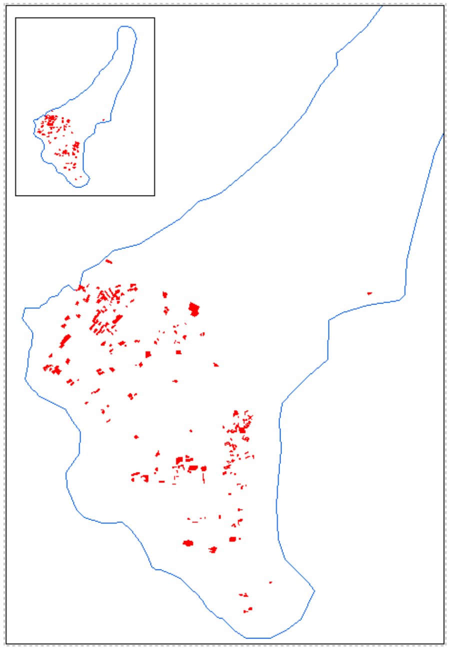
Abandon Cropland



Uncropped area,2012



Uncropped area,2013



Report abandon plot

2012uncropped- 2013crop

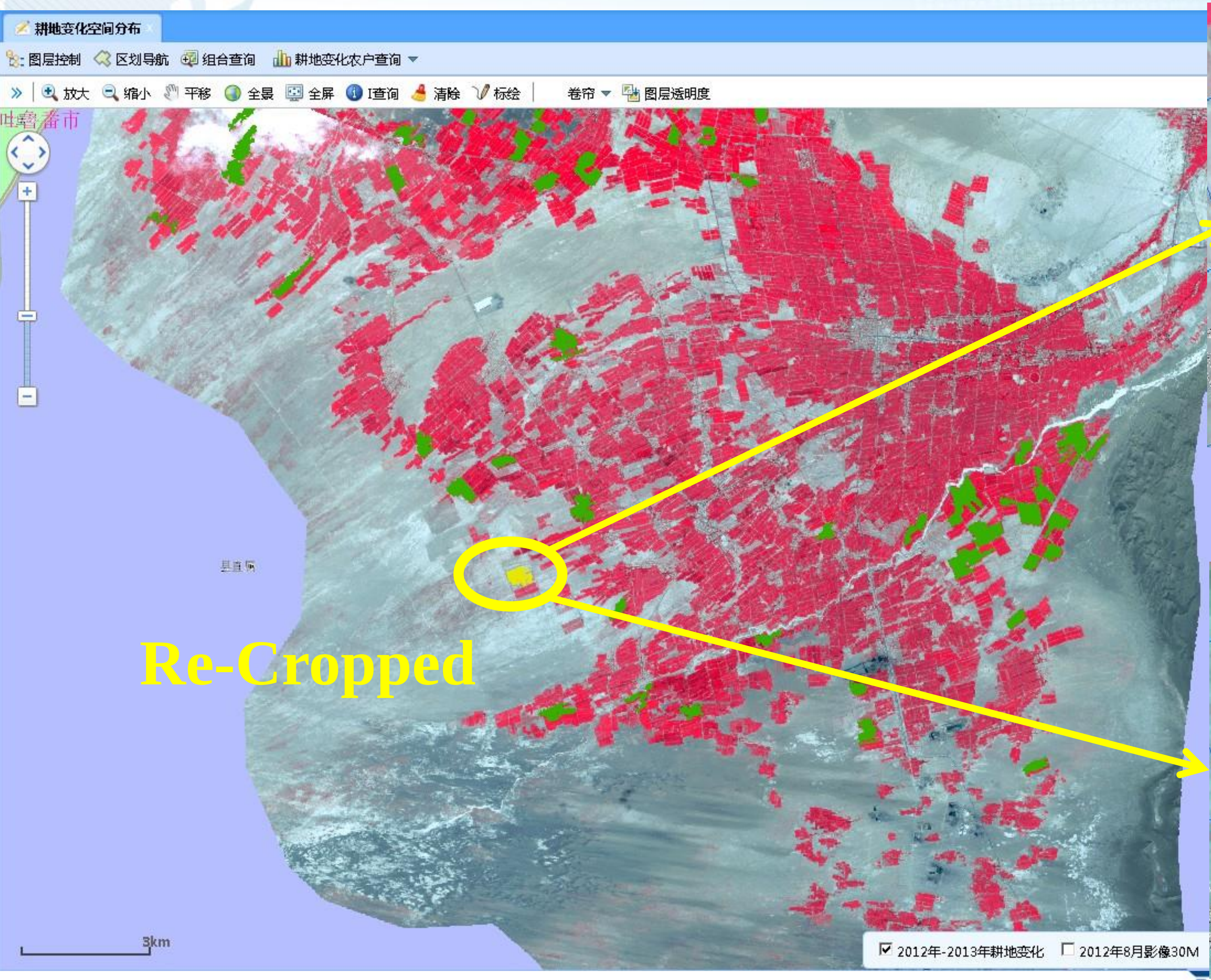
2012	2013	Area/ha
Uncropped	Grape	8.5
Uncropped	Cotton&Cotton-Mellon	39.7
Uncropped	Mellon	13.6
Uncropped	Other	5.6
Total		67.5

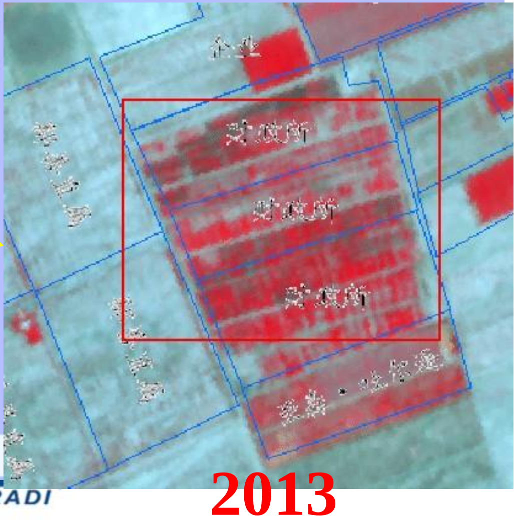
2012crop- 2013uncropped

2012	2013	Area/ha
Grape	Uncropped	28.0
Cotton&Cotton-Mellon	Uncropped	524.0
Mellon	Uncropped	56.0
Other	Uncropped	16.3
Total		624.3

- **Uncropped area in 2013 increased significantly (553ha)**
- **Reported abandon cropland in 2013 was 1226.3ha**

Reclaimed-Cropped Farmland Monitoring (ZY-3,spatial resolution: 5m)





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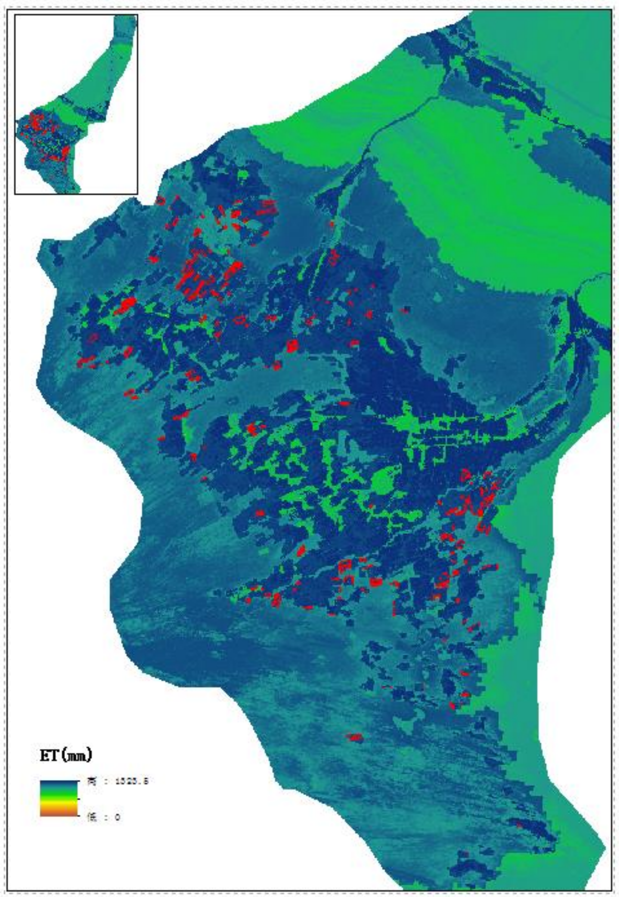
Abandon cropland



- Combined with ET, the farmer fields that ET larger than 100 were selected
- There are about 210 farmers(766.6ha) need to be checked and confirmed

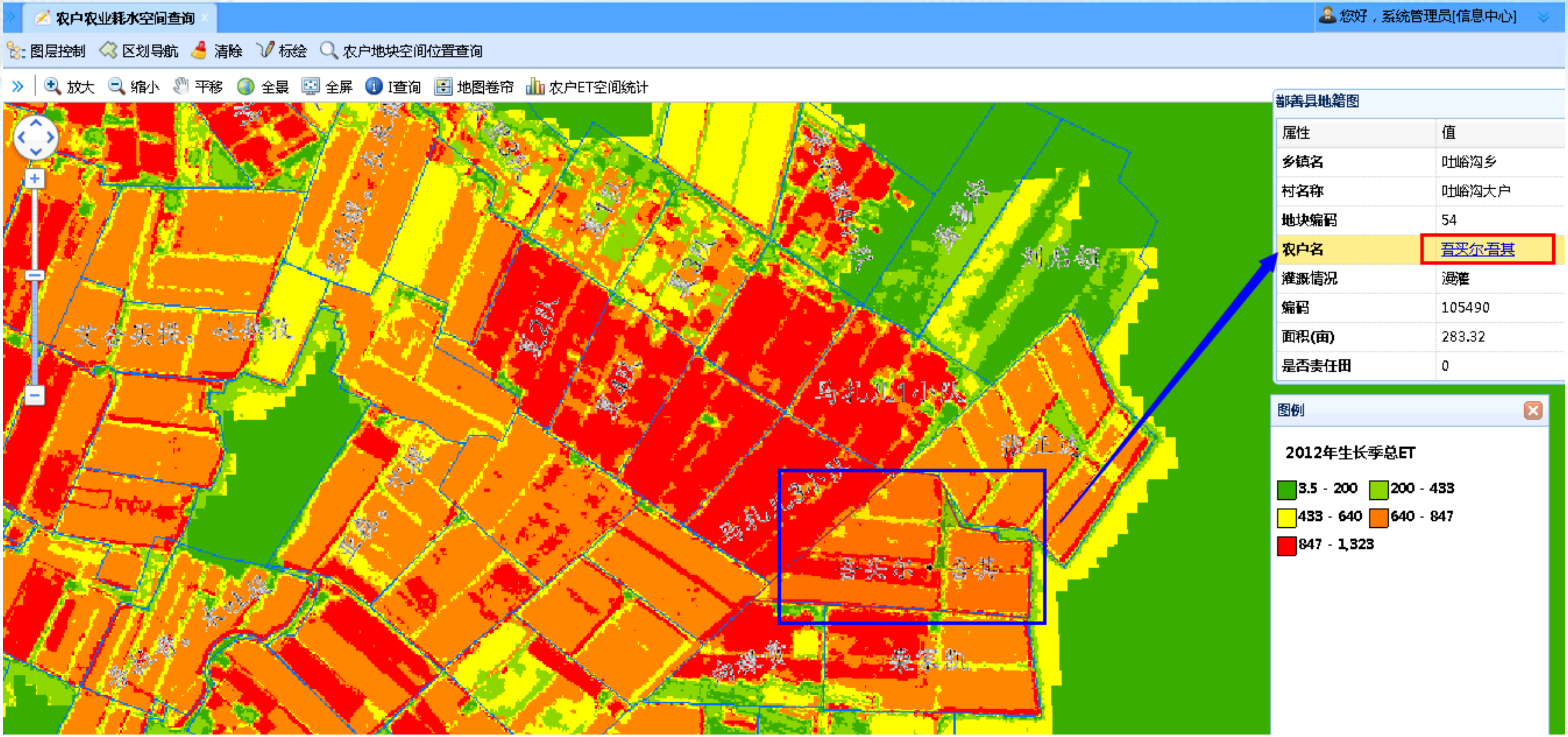
Crop planting area in reported list

	ha
Reported	**1226.3**
ET>100	**766.6**

Name list to be checked

户名	未退面积
供销社	355.96
戴国庆	231.75
张道富	230.10
史桐庆	221.96
玉素甫・合力力	215.03
供电所	197.19
亚森・克依木	195.28
排吐力・买买提	193.85
吴文清	167.09
沙元庆	151.54
买买提・苏莱曼	146.89
阿不力提甫・吾拉音	145.91
黄振芳	134.30
热西提・肉孜	133.96
吴恒斌	132.95
艾合买提・克依木	130.51
阿布力提甫・力提甫	122.23

Farmer’s ET Monitoring (5m)



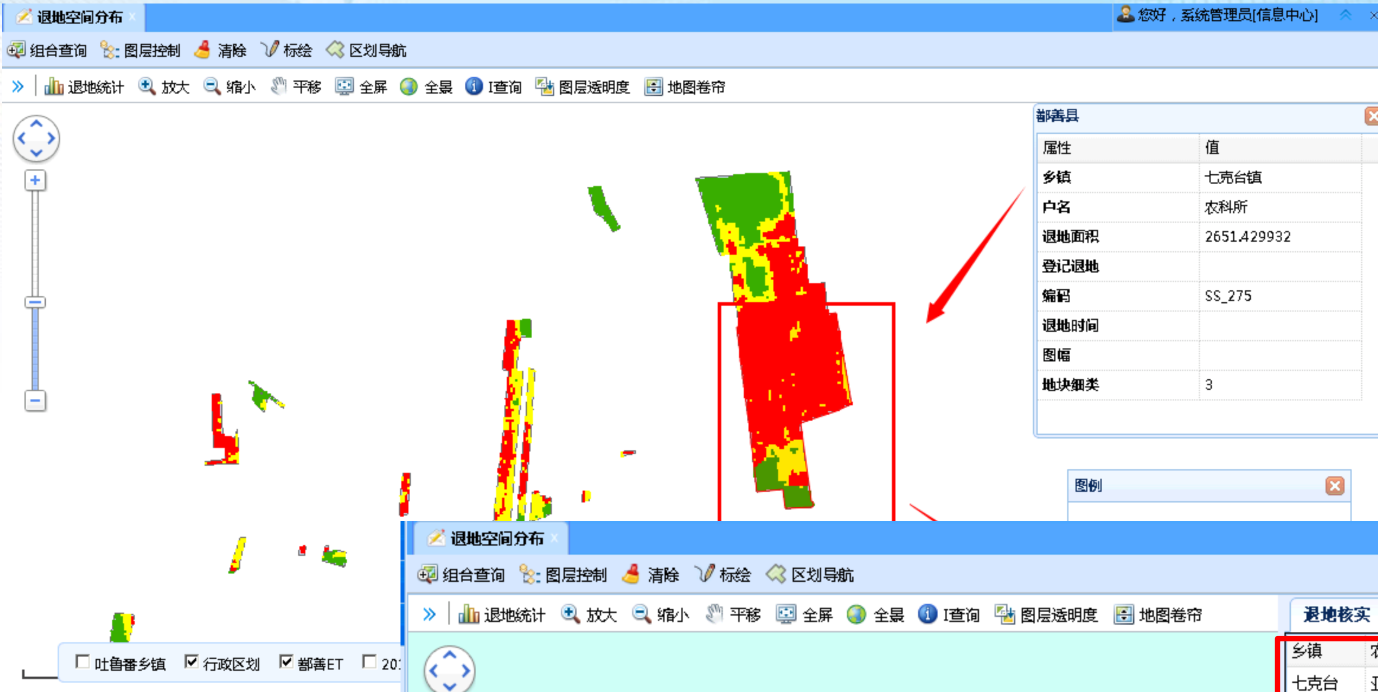
Farmer’s name, crop type, area and every month, total year’s ET and water consumption

农业农户耗水统计

执行统计　导出EXCEL

县级名称	乡镇级名称	村级名称	地块编码	农户名	作物类型	面积(亩)	年份	四月(mm)	五月(mm)	六月(mm)	七月(mm)	八月(mm)	九月(mm)	十月(mm)	生长季总量(mm)	总耗水量(m3)
鄯善县	吐峪沟乡	海洋3队	105490	吾买尔·吾其	葡萄	7.16	2012	30.56	114.12	169.14	182.88	163.13	89.87	20.87	770.57	3678.37
鄯善县	吐峪沟乡	海洋3队	105490	吾买尔·吾其	棉花或瓜套棉	275.82	2012	36.53	142.39	125.16	149.29	132.63	74.88	70.52	731.4	134497
鄯善县	吐峪沟乡	海洋3队	105490	吾买尔·吾其	棉花或瓜套棉	275.23	2013	14.57	42.61	136.97	126.36	106.27	61.55	46.54	534.86	98144.6
鄯善县	吐峪沟乡	海洋3队	105490	吾买尔·吾其	葡萄	7.76	2013	27.66	70.85	144.77	175.32	154.85	74.88	29.13	677.45	3504.85

Farmland Checking



Find the false Information (red color) by ET map

Query

ET > 100 mm

get all false Information list

Conclusion

- In order to ensure sustainable water use, the basin-wide agricultural water consumption shall be under the limitation.
- In water scarcity basin, if you want to increase water consumption in industrial and domestic sector, you have to reduce the water consumption from other sector, in fact only agricultural. Otherwise the consequence will be depletion of aquifer or shrink of lakes in the downstream
- Making ET management clear to policymakers is difficult, because the implications for food security (and farm incomes) are negative to water: And difficult to water engineers too, because new approach is different from they are educated